CHAPTER – 1

OVERVIEW TO CERAMIC SUPERCONDUCTIVITY

This chapter presents a brief overview of the ceramic superconductivity. The subject of the present thesis is to study the nature of attractive pairing mechanism leading to superconducting state, normal state resistivity, anisotropic magnetic properties, optical conductivity and as an application the current driven plasma instabilities in superconducting materials. In particular, this thesis addresses the problem for the formulation of an effective interaction potential of bismuth and copper based oxides. A number of theoretical approaches proposed to understand the pairing mechanism is first reviewed. Experimental observations on bismuth and cuprate ceramic superconductors are then explored with particular emphasis on the necessity of understanding the present investigations.
1.1 General Introduction

The liquefaction of liquid Helium by Kamerlingh Onnes at the beginning of this century has been a revolutionary event for the low temperature physics. The investigation of the properties of some simple metals cooled down to such low temperature leads to a remarkable discovery: their resistivity goes to zero below a well defined (and finite) temperature. Later on another striking feature of the superconducting materials has been shown by Meissner and Ochsenfeld [Meissner & Ochsenfeld33]: when subjected to a magnetic field and then cooled below $T_c$ (or vice versa), they expel the field lines.

The leading theoretical idea to explain such peculiar features is the formation of pairs and is nicely expressed in Gamow's limerick [Blatt64] on Ogg's bielectron theory [Ogg46]

*In Ogg's theory it was his intent
That the current keeps flowing, once sent;
So to save him trouble,
He put them in double,
And instead of stopping, it went.*

Gamow.

In the Fifties Ginzburg and Landau [Ginzburg & Landau50] faced the problem of superconductivity within the phenomenological approach, characterizing the appearance of the superconducting state through the presence of the microscopic quantum wave function of the condensate system. Later on Blatt, Schafroth and Schafroth *et al.* [Blatt64, Schafroth55, Schafroth *et al.*57] gave a semi-phenomenological description within a two fluid model; they postulated the coexistence of the resonant state of two electrons, statistically treated as pointlike bosons of charge $2e$, and unpaired electrons. However the experimentally found critical temperatures implied unrealistic carrier densities ($\approx 10^{17}$ cm$^{-3}$) and pair masses ($\approx 10^8$ electron masses). It took almost 40 years after Onnes' discovery before a fully satisfactory microscopic model for superconductivity was put forward by Bardeen-Cooper and Schrieffer [BCS57].

The Bardeen-Cooper-Schrieffer theory represents the standard theoretical framework for superconductivity. BCS theory allows the treatment of a fermion
fluid with an effective attractive interaction, which leads to the formation of a condensate of spatially overlapping pairs. The successful application of the theory of metal and alloy superconductors (the so-called conventional low temperature superconductors) is based on a phonon-mediated microscopic mechanism that is responsible for pairing in a momentum space.

Among the conventional materials, it appeared that the poorer was the normal state conductivity the higher the transition temperature ($T_c$). the best being Nb$_7$Ge with $T_c = 23.2$ K. On these grounds, it has been natural to pursue the search for higher critical temperature compounds among materials with stronger lattice polarizability and then enhanced electron–phonon coupling. Historically, this was the leading idea [Bednorz & Muller88] of George Bednorz and Alex Muller when they found in 1986

![Graph showing Superconducting Transition Temperature versus Year](image)

Fig: 1.1 Superconducting Transition Temperature versus Year

a new kind of material with $T_c = 30$ K [Bednorz & Muller86]. The material was La-Ba-CuO, the first of a new class of superconductors, and later on YBa$_2$Cu$_3$O$_{7-5}$ was discovered [Wu et al.87] broadly referred to as cuprates or cuprous oxides.
The discovery of superconductivity in perovskite oxide BaPb$_{1-x}$Bi$_x$O$_3$ ($T_c \approx 13$ K) [Sleight et al. 75] and the multiphased Ba-K-BiO [Mattheiss et al. 88] at 22 K and latter the identification of superconducting component as Ba$_{0.6}$K$_{1.4}$BiO$_3$ ($T_c \approx 30$ K) [Cava et al. 88] provides an opportunity to understand the nature of pairing mechanism as well as that of physical properties of metal oxides. In a few years the critical temperatures of superconducting materials grew up to 150 K in Hg based cuprates (Fig 1.1), well above the boiling point of liquid nitrogen.

The discovery of high-$T_c$ superconductors represents a new challenge for both experimental and theoretical physics. We report in Fig 1.2 the example of the resistivity curve of the materials, namely Ba$_{1-x}$K$_x$BiO$_3$ [Affronte et al. 93] and YBa$_2$Cu$_3$O$_{7-\delta}$ [Iye 92]. The resistivity of Ba$_{1-x}$K$_x$BiO$_3$ shows the metallic temperature dependence. The behaviour is not simply linear as is observed in most superconducting oxides and it looks similar to that of more conventional metals. Concerning the cuprates, they are very complex indeed and have quite unusual physical properties in the superconducting as well as in the normal state.

![Resistivity vs Temperature](image1)

![Resistivity vs Temperature](image2)

**Fig 1.2.** Variation of normal state resistivity ($\rho$) with temperature in Ba$_{1-x}$K$_x$BiO$_3$ and YBa$_2$Cu$_3$O$_{7-\delta}$ superconductors.

We first discuss about the phase diagram of bismuth oxides in Fig. 1.3. The parent compound BaBiO$_3$ is diamagnetic and the chemical substitution of the monovalent alkali metal, K, at the Ba sites makes the system metallic. The formal charge valence of Bi ions of BaBiO$_3$ is +4 and since neutral Bi atoms have five valence electrons, one free charge carrier (hole) exists at each Bi site. At lower
compositions, i.e. $x < 0.3$, the system displays semiconductor properties. Superconductivity occurs only in the cubic phase ($x \geq 0.37$) and has an undistorted cubic perovskite structure. For $x = 0.35$, a transition from the cubic to orthorhombic phase occurs between 200 and 100 K. Within this cubic phase $T_c$ is highest for the composition $x \approx 0.4$ at 30 K.

The phase diagram of La$_{2-x}$Sr$_x$CuO$_4$ is shown in Fig. 13. The parent La$_2$CuO$_4$ is a diamagnetic insulator and the doping of the divalent Sr at the trivalent La sites introduces free charge carriers (holes) in the conducting CuO$_2$ layer and the system behaves as metallic. At lower compositions, $x \leq 0.06$, the system behaves as a diamagnetic insulator. The superconductivity is reported in the wide range ($0.06 \leq x \leq 0.3$). However, it behaved like a normal metal at $x > 0.3$. For $x = 0.2$, a transition from orthorhombic to tetragonal phase occurs between 200 and 100 K.

![Fig. 1.3 (a) BaKBiO$_3$, and (b) (La$_{2-x}$M$_x$)CuO$_4$ phase diagrams. AF = Insulating Antiferromagnetic phase; $T_N$ = Neel temperature; $T_c$ = Superconducting transition temperature.](image)

Within this orthorhombic phase $T_c$ is highest for the composition $x \approx 0.15$ at 40 K. Similar is the situation in YBa$_2$Cu$_3$O$_{6.5}$ where the doping is done through extra oxygen content ($\delta$). The phase diagram shows how rich is the physics of these new materials, running from an antiferromagnetic insulator state to a metallic state, to superconductivity, to structural transitions between tetragonal and orthorhombic phases. It evidences also how crucial is doping in this variety of different physical states.
On the experimental side many technical problems are to be faced in the investigation of the high-$T_c$ compounds, in order to disentangle the features which are relevant to understand the underlying physics. The non-transition metal compound i.e., bismuth oxides are isotropic as the oxygen octahedra form a three-dimensional network and cubic in nature. Cuprates are strongly anisotropic and made of planes of copper and oxygen separated by planes of other oxides and rare earth elements. In addition, the structure of the synthesized samples can be twinned along the axis perpendicular to the CuO$_2$ planes. A further complication stems from the non-stoichiometric nature of these materials, which is crucial in order to span the whole phase diagram.

After more than a decade, the questions are many and still too difficult to be answered to. However some definite conclusions can be drawn, at least from the experimental viewpoint. The next sections contain a brief phenomenological description of high-$T_c$ metal oxides.

### 1.2 Crystal Structure

Let us start with a little presentation of the crystal structure of bismuth and cuprous oxides together with some needed nomenclature, which will be useful in the following.

The crystal structure of bismuth oxides is cubic (perovskite) in most cases are monoclinic phases. The electronic structure of BaPb$_{1-x}$Bi$_x$O$_3$ system, which has $T_c$ up to 13 K near $x = 0.25$ [Sleight et al. 75] has been studied in detail by Mattheiss and Hamann [Mattheiss & Hamann 83]. They have investigated both of the end members and alloys in virtual-crystal approximation and have studied both the cubic (perovskite) and monoclinic phases. The electronic structure is dominated by a ten-band complex around $\varepsilon_F$ arising from O-2p and Pb-Bi 6s states. The valence-band region contains two 16-eV-wide $\sigma$-bonding 2p-6s sub-bands, which have their centres near a number of nonbonding O-2p bands. The band structures lead to metallic behaviour for all $x$ in the cubic phase.
The Pb and K doped bismuth oxides show transitions from the high-temperature cubic structure to tetragonal ($x \approx 0.3$) and monoclinic ($x \approx 1.0$) structures at room temperature and display a metal-to-insulator transition near $x \approx 0.3$ (see Fig.1.4). Many of these features can be accounted for, qualitatively and in some cases quantitatively, by the band structure calculations. For example, a strong Fermi-surface-driven instability is predicted for the $x \approx 1.0$ member, which accounts for the stability of the monoclinic structure as well as its semiconducting behaviour.

Turning to cuprates the crystal structure is tetragonal (body-centred-$bct$) in most cases, possibly with small orthorhombic distortions. Cuprates can be thought as made of a given number of adjacent CuO$_2$ planes parallel to the $a$-$b$ plane of the tetragonal structure; the planes are separated by spacing layers of different composition. From this viewpoint, cuprates can be classified according to this number of CuO$_2$ planes per formula unit. This is the general recipe. Table 1.1 lists some of the so far synthesized high-$T_c$ materials, together with their structural characteristics.

As far as the notation is concerned, there are many possibilities in the literature; here it is considered the one which is made by the symbol of the metal-based compound followed by four numbers: each of the first three represents the chemical composition with respect to all the component atoms but copper and oxygen: the last one indicates the number of the adjacent CuO$_2$ planes. Y-based
compounds constitute an exception: only three numbers are present and they refer to Y, Ba and Cu chemical composition. In addition the La-based compound is traditionally simply referred to as La-214.

<table>
<thead>
<tr>
<th>General Formula</th>
<th>$T_c$ (max) (K)</th>
<th>n</th>
<th>Notation</th>
<th>Isolation Layers</th>
<th>Layers between two CuO$_2$ planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaPb$_{1-x}$Bi$_x$O$_3$</td>
<td>13</td>
<td>1</td>
<td>BPBO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba$_{1-x}$K$_x$BiO$_3$</td>
<td>30</td>
<td>1</td>
<td>BKBO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Nd$_{2-x}$Ce$_x$)CuO$_4$</td>
<td>30</td>
<td>1</td>
<td>Nd-214</td>
<td>NdO</td>
<td></td>
</tr>
<tr>
<td>(La$_{2-x}$Sr$_x$)CuO$_4$</td>
<td>38</td>
<td>1</td>
<td>La-214</td>
<td>LaO</td>
<td></td>
</tr>
<tr>
<td>YBa$<em>2$Cu$</em>{3}$O$_{7-x}$</td>
<td>92</td>
<td>2</td>
<td>Y-123</td>
<td>CuO$_2$</td>
<td>Y</td>
</tr>
<tr>
<td>YBa$<em>2$Cu$</em>{3}$O$_x$</td>
<td>80</td>
<td>2</td>
<td>Y-124</td>
<td>2 CuO$_2$</td>
<td>Y</td>
</tr>
<tr>
<td>HgBa$<em>2$CuO$</em>{2+x}$</td>
<td>94</td>
<td>1</td>
<td>Hg-1201</td>
<td>BaO, HgO</td>
<td></td>
</tr>
<tr>
<td>HgBa$<em>2$CuO$</em>{2+x}$</td>
<td>127</td>
<td>2</td>
<td>Hg-1212</td>
<td>BaO, HgO</td>
<td>Ca</td>
</tr>
<tr>
<td>HgBa$<em>2$CuO$</em>{2+x}$</td>
<td>137</td>
<td>3</td>
<td>Hg-1223</td>
<td>BaO, HgO</td>
<td>Ca</td>
</tr>
</tbody>
</table>

Table 1.1 List of some high-$T_c$ compounds. From left to right: the general formula, the critical temperature, the number $n$ of CuO$_2$ planes, the notation of the compound, the composition of the isolation layers and the composition of the layers between the adjacent CuO$_2$ planes.

From the Table it appears also that the higher is the number of CuO$_2$ planes, the higher the transition temperature. In addition, adjacent CuO$_2$ planes sandwich a layer of alkali or rare earth atoms. Fig. 1.5 displays the layered structure in a unit cell representation for some of cuprates.
1.3 Superconducting state properties:

1.3.1 Critical temperature

A universal relationship between the critical temperature and the hole density in cuprates has been pointed out by Zhang and Sato [Zhang & Sato 93] and is shown in Fig. 1.6. Plotting for every cuprate the critical temperature normalised to its maximum one as a function of the hole content, it is found that all the compounds share the same universal curve. Muon-spin-relaxation have been extensively used to measure the correlation between $T_c$ and London penetration depth $\lambda_L$ and therefore the ratio of the superconducting density $n_s$ to the superconducting mass $m^*$ [Uemura et al. 91a, 91b].

Fig. 1.5 Schematic representation of elemental unit of cuprates.

Fig. 1.6 Critical temperature normalised to $T_c^{\text{max}}$ for a number of cuprates plotted as a function of the hole content per CuO$_2$ unit. Different symbols refer to different families.
1.3.2 Isotope effect

Isotope effect data in bismuth and cuprous oxides have been controversial for a long time. At the very beginning no correlation between critical temperature and isotope substitution had been found, leading to the conclusion that lattice excitations had not any role in the pairing mechanism. Now it is clear that $T_c$ changes when $^{16}$O is substituted with $^{18}$O, while rare earth elements substitution does not affect the critical temperature, even though some measurements seem to support the existence of an isotope effect due to copper substitution [Crawford et al. 90, Bill et al. 98]. BCS applied to conventional superconductors predicts $T_c \propto \omega_D \propto M^{1/2}$, where $\omega_D$ is Debye frequency. $\alpha$ is isotope effect exponent and $M$ is isotope mass.

A reduced oxygen isotope effect ($\alpha_0 \sim 0.2$) [Batlogg et al. 88] in Ba-K-BiO, have been reported, while the other groups [Kwok et al. 89, Kondoh et al. 89] observed a large oxygen isotope effect ($\alpha_0 \sim 0.3-0.4$). It appears that the result reported by Batlogg et al. looks convincing for two reasons. One is that the isotope-exchange temperature is low ($\sim 350^\circ$C) so that the loss of potassium is not expected. The second reason is that the observed oxygen isotope effect for Ba-K-BiO is similar to that for a similar compound BaPb$_{0.75}$Bi$_{0.25}$O$_3$ [$\alpha_0 = 0.22$].

Switching to copper oxides the Fig. 17 shows the oxygen isotope exponent $\alpha$ ($\alpha = \frac{1}{2}$ in BCS case) as a function of the hole concentration per CuO$_2$ plane in Y-Ba-CuO. $\alpha$ decreases as a function of doping, starting from the BCS value at very low doping and reaching negligibly small value in correspondence of the optimally doped sample.

![Fig. 17 Oxygen isotope exponent $\alpha$ (right) for Y-123 with number of mobile holes (charge carriers) per CuO plane $\Delta p$.](image)
Negative values of $\alpha$ have also been reported [Franck94]

1.3.3 Flux quantization
One of the striking features of the superconductors is the magnetic flux quantization. Since the system is characterised by a macroscopic wave function (the order parameter), the flux $\phi$ of the magnetic field through the superconductor is an integer number $n$ times a flux quantum, $\phi_0 = \hbar c e^*$. $\hbar$ and $c$ being the Plank constant and the velocity of light, respectively. The quantity $e^*$ is the charge of the superconducting carriers and can be deduced from the measure of $\phi$.

1.3.4 Specific heat
Specific heat measurements in superconductors are an important probe for electronic, phononic as well as magnetic excitations. However the high critical temperature and high critical fields $H_{c2}$ in high-$T_c$ materials make it difficult to disentangle the different contributions because lattice specific heat dominates at such temperatures.

One of the striking predictions of BCS is on the electronic specific heat jump at the critical temperature. If $C_{es}$ and $C_{en}$ are the superconducting and normal electronic specific heats respectively, then $(C_{es} - C_{en})/\gamma T_c = 1.43$. The quantity $\gamma = 0.66 \pi^2 k_B N(\varepsilon_F)$ is related to the electronic specific heat of a normal metal through the relation $C_e = \gamma T$ ($N(\varepsilon_F)$ is the density of states at the Fermi level and $k_B$ the Boltzman constant). A typical BCS value for $\gamma$ is $38$ mJ/mol K$^2$.

Low temperature specific heat measurements have been extensively used to analyze the bulk properties of these superconductors near the critical transition temperature ($T_c$) as well as for small temperatures. A common feature of low temperature specific heat measurements in cuprates is the linear behaviour with temperature and a jump in $C/T$ at $T_c$ [Kumagai et al. 88]. In the context of cuprate superconductors, Dunlap et al. [Dunlap et al. 87] have measured the specific heat of La$_{1.85}$Ba$_{0.15}$CuO$_4$ as a function of temperature ($T$) and observed that below $10$ K $C$ varies linearly and is dominated by the lattice in the vicinity of $T_c$. 

11
Subsequently, Nieva et al. [Nieva et al. 87] have reported $C$ of La$_{1.8}$Sr$_{0.2}$CuO$_4$ between 4 and 60 K and found an upturn in $C$ at $T_c$ as well as a linear term at low temperatures with a slope of $(4 \pm 2)$ mJmol$^{-1}$K$^{-2}$. Furthermore, Reeves et al. [Reeves et al. 87] have also reported the variation of $C$ and $T$ for both Ba and Sr doped lanthanum cuprates. On the other hand, Wenger et al. [Wenger et al. 87] have shown a clear absence of a specific heat anomaly at the superconducting transition temperature in La$_{1.85}$Ba$_{0.15}$CuO$_4$ from calorimetric measurements indicating that superconductivity is not a bulk property in these oxides.

In context to Y-Ba-CuO superconductors, Inderhees et al. [Inderhees et al. 87] have reported the precise measurement of the jump in specific heat associated with the superconducting transition. They predict that with decreasing temperature, $C_p$ exhibits a step like increase to a maximum at 90 K. The step change $C_p = 6.2$ mJ/gK is observed at $T_c$. Later on Braun et al. [Braun et al. 88] have done the measurement of the electronic specific heat anomaly in Y-Ba-CuO superconductors. They found a clear jump in $C(T)$ of the superconducting version at $T_c$ and also the jump in the normal state curve around 270 K. The experimental results are well fitted by a power law and yielded $\gamma = 7.5 \pm 0.5$ mJmol$^{-1}$K$^{-2}$.

Bessergenev et al. [Bessergenev et al. 95] have reported the experimental results of the heat capacity for the superconducting yttrium ceramics YBa$_2$Cu$_3$O$_6$$_{.92}$ in the temperature interval 5 to 300 K. Using the moments of phonon density of states they have estimated the coefficient of electronic heat capacity as $25.09 \pm 0.25$ mJmol$^{-1}$K$^{-2}$ for YBa$_2$Cu$_3$O$_6$$_{.92}$ with $T_c = 92.2$ K. Following layered electron gas approach within the Fermi liquid description, Varshney et al. [Varshney et al. 97a; 98a] have succeed in revealing the anomalous specific heat behaviour in La-Sr-CuO and Y-Ba-CuO superconductors. The calculations also estimates the electronic specific heat coefficient ($\gamma$) at $T_c$ and density of states at the Fermi level.

### 1.3.5 Coherence length

Short in-plane coherence lengths $\xi$ have been determined for some of the cuprate superconductors: about 30 Å for La$_{2-x}$Sr$_x$CuO$_4$ [Batlogg et al. 87], 36 Å for YBa$_2$Cu$_3$O$_7$ [Poole et al. 88], 40 Å for YBa$_2$Cu$_4$O$_8$ [Bucher et al. 90] and 60 Å for...
Nd$_{2-x}$Ce$_x$CuO$_4$ [Klauda et al. 90]. Since the in-plane lattice parameter $a$ is about 4 Å, these results give $\xi/a \approx 7.5$-15.0. These results are enormously different from the typical $\xi/a$ ratios of $\approx 10^3$ for conventional systems. It is quite remarkable that several other exotic superconductors are found to have nearly the same $\xi/a$ ratios.

It is anticipated that for the other exotic superconductors the relative importance of the conventional phonon mechanism is greater, i.e., that the "new" mechanism is acting relatively more weakly, so that the latter does not totally dominate over the former. One should than expect $\xi/d_{in}$ ($d_{in}$ is the in-plane spacing for the two-dimensional materials) to exhibit some intermediate value, greater than 2.5-3.5 but less than the $\approx 10^3$ typical for conventional superconductors. Such intermediate values are indeed common within the various exotic material families.

A qualitative conclusion follows from these examples of small $\xi/d_{in}$: a significant degree of pairing must exist throughout a major fraction of the Brillouin zone, and perhaps in the entire Brillouin zone, at least for the smallest-$\xi/d_{in}$ cases. This is clearly a major difference over the conventional superconductors.

1.3.6 Penetration depth
All of the exotic materials to date are intrinsic type-II superconductors. $k = \lambda_L/\xi \gg 1$ and typically $k > 10$. The exotic superconductors are therefore strong or extreme type-II materials. It is not clear yet whether the converse is true, but this conclusion is very appealing. Any strongly type-II material should therefore be examined for other signs of exotic behaviour. In addition to $\xi$ being anomalously small, the penetration depth $\lambda_L$ is anomalously large. In simplified theory (ignoring band-structure details) one finds $\lambda_L^{-2} \approx n m^*$. where $n$ is charge-carrier density and $m^*$ is an effective mass. The $\lambda_L$'s are anomalously large because $n$ is anomalously small, and also because $m^*$ is usually anomalously large.

The charge-carrier density $n$ is typically of order one per formula unit, or more accurately, per active ($U$-bearing) site or cluster. This makes $n$ conspicuously small compared to ordinary metals, because the exotic materials typically have a large volume (and many atoms) per formula unit. The effective mass $m^*$ tends to be large for two reasons: On the one hand, conventional band calculations usually
show that these are narrow-band or high state-density materials. (Exceptions are the bismuthate Ba-K-BiO and NbN).

On the other hand, in cases where an $m^*$ (or a state density) has been determined empirically, this $m^*$ tends to be even larger than in the band calculation. In the superconducting cuprates the mass enhancement factor due to many-body effects is $\geq 2$. This is based on the band-theoretic width for the antibonding $pd\sigma$ band, typically about 3.5 eV, and an estimate of about 1.4 eV for the corresponding empirical bandwidth, obtained from tight-binding band structure fits to angle-resolved photoemission data for a number of cuprates [Dessau et al. 93].

In most of the cases, it is clear that a substantial part of the mass enhancement cannot be due to electron-phonon coupling. In the case of cuprates, angle-resolved photoemission and inverse photoemission have observed the reduction of quasiparticle dispersion over an energy range of $|\epsilon_k - \epsilon_F| \leq 0.3$ eV beyond which the quasiparticle peaks become too broad to resolve [Dessau et al. 93, Mante et al. 90]. This energy range is far greater than the range of phonon energies for these materials ($\hbar\omega \leq 0.08$ eV). Such mass enhancement over an extended energy range is a typical consequence of strong correlation, as expected for a large $U$ interaction.

1.3.7 Superconducting gap

The gap ratio $2\Delta/k_B T_c$ sometimes has the ordinary BCS magnitude, $\approx 3.5$ (e.g. in $K_3C_{60}$ and $Rb_3C_{60}$ [Kiefl et al. 93, Degiorgi et al. 94], in BaKBiO [Sato et al. 90], and in LiTi$_2$O$_4$ [Ekino & Akimitsu 90], or somewhat larger (e.g. 3.7 in NbSe$_2$ [Clayman and Frindt 71], 4.0-4.3 in other studies of BaKBiO [Samuely et al. 93], and 4.0 in another study of LiTi$_2$O$_4$ [Ng et al. 87], but it is also sometimes much larger, being $\sim 5$-8 for cuprates [Batlogg 91, Schlesinger et al. 90]. The break-junction tunnelling study of single-crystal La$_{1.85}$Sr$_{0.15}$CuO$_4$ shows gap ratio of 8.9 $\pm$ 0.2 [Ekino et al. 96].

Larger gap ratios of 5.0 to 10.8 have been estimated for the heavy-fermion superconductors by fitting the decrease of $1/T_1$ below $T_c$ in NMR, assuming a gap form with line nodes [Kyogaku et al. 92]. But this procedure assumes a standard BCS temperature dependence for the gap magnitude, which may well be wrong and
which can thus invalidate the results. Enlarged gap ratio upto 4.46 (Nb₃Al) [Mitrovic et al. 84] and 4.9 (Nb₃Sn) [Junod82] have been found in A-15 materials. These latter ratios are reasonably consistent with the strong-coupling Eliashberg theory, although it is worth noting that the A-15 materials exhibit relatively large deviations from the general trend of the more conventional strong-coupling materials [Marsiglio & Carbotte 86].

1.3.8 Gap symmetry

The topic of the cuprate gap symmetry is a departure from our rule that only features found in several of the exotic material families. It is worth to comment on this issue not only because this is such a famous and much-discussed problem, but also because this is relevant for the overall picture of the exotic superconductors. This issue certainly cannot be settled here. The status of the available evidence has been reviewed many times [Dynes94, Van Harlingen95], usually with conclusion that symmetry is probably d-like, i.e., changing sign when the tetragonal CuO₂ plane is rotated 90°. It is believed that this conclusion is premature, because of some experimental problems and also because of considerable evidence to contrary.

There is indeed some apparently strong evidence for the d-wave case, due to a number of phase-sensitive experiments using Josephson tunneling in a variety of geometry's [Dynes94], and there is consequently now a widespread opinion that this evidence has settled the issue. But there is also some contrary evidence, which indicates that this issue is not settled yet. At the outset it should be recognized that most and perhaps all of these “d-wave” experiments are subject to problems which could falsify their conclusions.

Furthermore, much of the other (non-quantum-interference) evidence, which is claimed to support a d-wave gap, is actually only evidence for gap nodes. It is important to recognize that gap nodes are also allowed in the highly anisotropic s-like case [Mahan89] — s-like in the sense of having no sign change under rotation by 90°. (In general, by “s-like” we mean a gap having the full point-group symmetry of the lattice.) In the cuprate case the tetragonal symmetry of the CuO₂ planes strongly suggests that an s-like anisotropic gap should have either no nodes or eight nodes. Both of these cases can be qualitatively described as “s+g” gap
forms, where \(^g\) refers to a real \( \cos^4 \theta \) component: the difference between these cases arises from relative strength of the \(^g\) component.

1.4 Normal state properties

1.4.1 Resistivity

AFFRONTE et al. [AFFRONTE et al. 93] have reported resistivity data for a single crystal of Ba\(_{1-x}\)K\(_x\)BiO\(_3\) (0.35<\(x\)<0.4) and found that the resistivity (\( \rho \)) shows a metallic temperature dependence. The behaviour is not simply linear as is observed in most superconducting oxides and it looks similar to that of more conventional metals. Later on, the resistivity analysis [Golovashkin et al. 94] reveals that \( \rho \) as a function of temperature is quadratic at low temperature (\( T<180 \) K) and rises linearly with temperature when \( T > 200 \) K. The quadratic temperature dependence of \( \rho \) is interpreted in terms of dominant electron-electron interaction at low temperatures.

Departures from the linear behaviour are observed for instance in the case of Nd- and La- based compounds. Moreover it is worthwhile to mention that the in-plane resistivity of YBa\(_2\)Cu\(_4\)O\(_8\) is fittable with the Bloch-Gruneisen formula [BERGHIUS et al. 90]. Anyway, the linear dependence is mainly peculiar of the (nearly) optimum doped samples. In the so called overdoped region, where \( T_i \) falls down from the maximum value at optimum doping, the dependence is still power law-like, \( \rho_{ab} \approx T^\gamma \); however in this case the exponent \( \gamma \) varies from 1 to 2 as far as the doping is increased [IYE92]. \( T^2 \) dependence would be consistent with a dominant contribution from electron-electron scattering within a Fermi-liquid picture.

An exception to the cited behaviour seems to be the fully oxygenated Y-Ba-CuO sample. However Y-Ba-CuO compound is peculiar in the cuprates panorama, because it has the chains which are fully occupied in the fully oxygenated Y-Ba-CuO case; keeping in mind that the \( b \)-axis conductivity has contributions from the plane and from the chains whereas the \( a \)-axis one contribute only to the planes, a straightforward analysis of the data shows that about the 60\% of the conductivity comes from the chains [FRIEDMAN et al. 90].

A direct evidence of this fact comes from the experiments of Bucher and Wachter [BUCHER & WACHTER95] that have investigated the transport and optical properties of YBa\(_2\)Cu\(_{3.5}\)O\(_{7.5}\). In this case the contribution from \( a \) and \( b \)-axis can be
more easily disentangled because $\text{YBa}_2\text{Cu}_3\text{O}_{6-\delta}$ is entwined. The resistivity along the chains shows a $T^2$ dependence on the temperature up to 500 K. The resistivity in the planes has an unconventional behaviour, it being linear in $T$ for temperatures larger than 160 K. The effect of oxygen deficiency on the normal state resistivity of $\text{YBa}_2\text{Cu}_3\text{O}_{7.5}$ superconductor have been investigated within the framework of layered electron gas approach. The results show the importance of interlayer acoustic phonon on the normal state resistivity behaviour with temperature and oxygen deficiency [Varshney & Singh95a; Varshney et al.98b]

As far as the c-axis resistivity is concerned, it often shows an upward curvature near $T_c$, which is reminiscent of a semiconductor like behaviour. However, if this would be actually the case, the temperature dependence would be exponential, like for a thermally activated process; on the contrary, $\rho_c$ still have a power low dependence with $\gamma$ varying from 0 to 2 depending on doping [Carrington et al.93]. The upward curvature tends to disappear with increasing the doping, when the anisotropy reduces too.

Summarising, the resistivity of cuprates has a power law dependence on temperature, the exponent ranging from 1 to 2 for $\rho_{ab}$ and from 0 to 2 $\rho_c$. The exponent varies upon overdoping the sample, the optimum doping $\rho_{ab}$ being linear in $T$. It is not at all clear if the unusual behaviour of the resistivity in cuprates is built up with their anisotropy and nearly two-dimensional character or it comes about from a particular microscopic mechanism.

1.5. Theories of High Temperature Superconductors

From a theoretical point of view, high-$T_c$ superconductivity has attracted researchers with different backgrounds and technical languages. Looking once again at the phase diagram in Fig. 1.3 it is not surprising that many different microscopical pairing mechanisms have been proposed to explain superconductivity in bismuth and cuprous oxides. In fact, the excitations that could lead to effective attractive interaction may have different origin, either phononic, magnetic, or pure electronic correlation effects or even a co-operation of two or more of them. The point is that whatever the mechanism is, it must be sufficiently strong in order
to account for the observed short coherence length of the new materials with respect to the conventional ones.

Many theories have been put forward to explain the attractive pairing mechanism, among which the Resonating Valence Bond (RVB) theory by Anderson [Anderson87, Anderson et al 87]. purely electronic mechanism like the exciton-coupling by Varma et al.[Varma et al.87], the collective excitations [Ruvalds87, Jha87], the phonon mechanism with strong coupling and plasmon mechanism [Kresin87], spin bags by Schrieffer et al. [Schrieffer et al.88], the spin fluctuation model by Pines and co-workers [Pines et al.90] and bipolaron models, first proposed by Alexandrov and Ranninger [Alexandrov & Ranninger81, Alexandrov et al.86].

On a less exotic side, some attempts have been made in order to go beyond the Eliashberg theory [Eliashberg60] for strong electron-phonon coupling and overcome the Migdal theorem limitations [Migdal58, Pietronero & Strasser92]. Remaining within the Eliashberg formalism, it has been shown that the right $T_c$ values and other doping dependent properties can be obtained, provided that $\varepsilon_F$ pins on a logarithmic van Hove singularity in the density of states, as it appears from band structure calculations [Tsuei et al.90]. In this case there is no need for unusually large electron-phonon coupling parameters.

In the next subsection we shall focus on the phononic and the non-phononic models applied to ceramic superconductors.

1.5.1 Phonon mechanism

For the phonon mechanism of superconductivity, that is, when the attraction between electrons is due to virtual exchange of lattice vibrations (BCS theory), the transition temperature in the weak coupling limit is given by, $T_c = 1.14 \theta_D \varepsilon_F^{-1} \lambda$. for the coupling strength $\lambda = N(\varepsilon_F) l'<<1$. It is obvious that the factors that can lead to an increase in $T_c$ are: an increase in Debye temperature $\theta_D$, density of electron states $N(\varepsilon_F)$ at the Fermi energy and/or interaction $l'$ responsible for pairing.

Superconductors obtained before 1986 were characterised by parameters leading to $T_c \leq 25$ K and in view of rough estimates including realistic predictions
for \( \lambda \) and \( \theta_D \), it is usually concluded that \( T_c < 30-40 \) K using only a phonon mediated interaction were unlikely. A number of studies have attempted to account for the large value of \( T_c \) for oxide superconductors in terms of the exchange of phonons between electrons. However, the reduced or vanishing oxygen isotope effect in the oxides and lack of evidence for strong electron–phonon coupling in inelastic neutron scattering studies have established that phonon pairing may be contributing to the high-\( T_c \) but not as the primary mechanism.

### 1.5.2 Exciton Mechanism

The pairing interaction between conduction electrons, which leads to superconductivity, may be caused by excitations other than phonons. The possibility of obtaining superconductivity at temperatures approaching room temperature by utilising an electronic excitation rather than a phonon mechanism was first suggested by W.A. Little [Little64]. The original proposal was based on the concept of deliberately designing a polymeric system with certain electronically polarizable side-chains to provide the electronically mediated attraction. Later on, Ginzburg [Ginzburg68,70] suggested a 2-D analogue of organic superconductor consisting of a sandwich of an atomically thin metal layer between layers of dielectric as illustrated in Fig. 1.8.

![Fig. 1.8 Ginzburg's 2-D exciton superconductor.](image)

The essential aspects of these two model systems are that the conducting core of the one-dimensional (1-D) polymeric structure and the metallic intralayer of
the dielectric-metallic-dielectric structure provide the conducting medium while the single chains and dielectric layers provide a favourable medium for the exchange of electronic excitations, that is, excitons. Such excitation can not be sustained within a conducting, nearly free system. Electron from the conducting portion of this structure would drift into the highly polarizable exciton rich side structure and exchange excitations in the fashion similar to conventional phonon mediated interactions.

As with the phonon interactions, the excitonic effective electron-electron interaction would be localized in space but delayed in time. Very thin structures characterised by 1-D conducting cores in the polymeric system and the near mono-layer metallic planes of the hetero-structure proposed by Ginzburg are necessary because as \( T_c \) increases, the coherence length \( \xi \) will decrease, i.e. \( \xi \approx k_B T_c / \hbar \nu_f \), and pairing will only be sustained for scales comparable with \( \xi \). The critical range in phonon mediated prediction for \( T_c \) brought about by exciton exchange is the replacement of \( \theta_D \) as the prefactor to the exponential term in the BCS expression for \( T_c \) by an electronic energy which may be one or two orders of magnitude larger than \( \theta_D \). Thus the exciton model would lead to the BCS like expression given by, \( T_c \approx \theta_E e^{-1/\lambda} \) where, \( \theta_E \) is an electronic energy of the order of \( 5 \times 10^3 - 5 \times 10^4 \) K and \( \lambda \) is \( N(\epsilon_F) \nu_{ex} \), the effective exciton mediated electron-electron attraction potential.

The Ginzburg hetero-structure model has some similarity to the high-\( T_c \) oxides. Namely, these systems are all composed of 2-D conducting planes embedded in the low conducting medium perpendicular to the conducting planes. In good metals, there is another type of collective excitations, namely plasmons, with excitation energy \( E_p = \hbar \omega_p \leq \epsilon_F \), which can also be exchanged in the fashion similar to that discussed above and used in the phonon model. For the free electron gas, the plasmon frequency is given by \( \omega_p = (4\pi n e^2/m)^{1/2} \). The plasmons being considered here are longitudinal vibrations in the density of conduction electrons and their exchange does not take into account the effect of other bound electrons. These density fluctuations are found to contribute in the simplest case only towards the screening of the Coulomb interaction and influence the parameter \( \mu \). Usually the
frequency $\omega_{pl}$ considerably exceeds $\omega_D = k_B T_D / \hbar$. For example, for exciton energy $E_x = \hbar \omega_p \approx 0.1 - 1 \text{eV}$, $\theta_{pl} \approx 10^3 - 10^4 \text{K}$ as compared to typical $\theta_D \approx 100 - 500 \text{K}$.

As indicated above, the large enhancement of $T_c$ using the exciton or plasmon mechanism primarily results from the replacement of $\theta_D$ by $\theta_{pl}$ or $\theta_E$ in the BCS formula. In the exciton mechanism, bound electrons play the role of ions with mass, which is generally of the order of the mass of a free electron. Hence, $\theta_{pl} (\approx (M/m)^{1/2} \theta_D) \approx 300 \theta_D$ and this higher $\theta_{pl}$ leads to a much higher $T_c (\approx 300 \text{K})$ than to that in the phonon mechanism. However, as in the electron-phonon case, when the coupling increases, the collective modes soften, ultimately going to zero frequency, followed by a static charge distortion, that is, a charge density wave. In order to prevent an instability in the conduction electron gas, the dielectric constant $\varepsilon(q,0)$ resulting from the phonon and all electronic excitons would have to be positive. Using an exciton mechanism, Little [Little73] showed that there is no fundamental principle prohibiting the attainment of high temperature superconductivity. This excitonic mechanism has been extensively discussed in recent literatures [Kresin et al.93] and applied to new high-$T_c$ oxides.

1.5.3 Plasmon mechanism

Plasmon and other bosonic mechanisms have been widely discussed [Chan et al.87, Ihara et al.87, Ruvalds87, Jha87], Kresin [Kresin87], Tewari & Gumber [Tewari & Gumber90], Bassani et al. [Bassani et al.91], Varshney & Singh [Varshney & Singh95b], Legett [Legett99] and Varshney & Tosi [Varshney & Tosi99a, 99b] concluded that the high-$T_c$ mainly arises from the contributions of plasmons. High-resolution electron microscopy techniques have been used to probe the electronic structure of copper oxide superconductors. Electron energy loss spectroscopy (EELS) reveals a free carrier plasmon at energy of about 1-2 eV [Bozovic90]. The charge fluctuations are large in cuprates and thus it is expected that they play a significant role.

There is IR-Raman evidence for plasmons in Y-Ba-CuO [Perkowitz et al.87] and La-Sr-CuO [Schlesinger et al.87] and a mechanism was proposed for La-Sr-CuO [Lee & Ihm87] involving an attractive interaction between plasmons in a band composed mainly of Cu $d_{x^2-y^2}$ and oxygen 2p orbitals and electrons in a lower band.
formed from copper d_z and oxygen 2p orbitals. Pair breaking arising from electron-phonon and electron-electron scattering suppresses \( T_c \), relative to energy gap, leading to \( E_g/k_B T_c \) values in excess of the BCS one of 3.5.

### 1.5.4 Polarons and Bipolarons

The effect of polarons on producing high \( T_c \)'s has been discussed [Alexandrov et al. 87, Kuramoto & Watanabe 87, Little et al. 87, Robas et al. 87, Scalapino et al. 87]. Photoconductivity data indicate that an ensemble of polarons and excitons plays a substantial role in the mechanism of high temperature superconductivity [Mazumdar 87, Masumi et al. 87].

Retardation effects on the longitudinal optical (LO) phonon exchanges between two Frohlich polarons were shown to be attractive. This is analogous to the van der Waals interaction between neutral atoms, which involves the retardation effect (or phase delay) due to the finite velocity of the virtual photons that are exchanged. The value \( T_c \approx 200 \text{ K} \) with \( E_g/k_B T_c \approx 1.3 \) may be attainable for a LO frequency of \( 2 \times 10^{14} \text{ Hz} \). This model [Yi et al. 87] predicts that as \( T_c \) increases the ratio \( E_g/k_B T_c \) decreases and approaches 1.47 as \( T_c \to \infty \).

The possible role of bipolarons has also been examined carefully [Alexandrov et al. 86]. In one approach involving an extended Hubbard model, the singlet superconducting state is unstable toward disordering if the intersite interaction is attractive and it is unstable toward a charge-ordered superconducting state if the intersite interaction is repulsive [Hirsch 87, Mazumdar 87]. Another such work [Wysokinski 87] determined the phase diagram of \( \text{La}_{2-x} \text{M}_x \text{CuO}_4 \) as a function of \( x \), and also provided the expression: \( E_g/k_B T_c = \ln[(2-x)/x]/(1-x) \). In this approach the superconducting state is due to localized or real state pairs, and the low-temperature specific heat is believed to vary as a power of \( T \).

### 1.5.5 Resonating Valence Bond Model

The RVB model was proposed by Anderson [Anderson 87, Anderson et al. 87]. The model is based on the properties of missing charge carriers (electrons or holes) introducing by doping in high-\( T_c \) cuprates. Anderson proposed that the pairing interactions in La-214 and Y-123 systems are magnetic in origin. It is based on the
idea that Cu$^{2+}$ ions are magnetic and the magnetic moments on neighbouring sites are antiferromagnetically aligned due to the super-exchange interaction through interacting oxygen. If the antiferromagnetic ordering is frustrated due to the geometry, low dimensionality, or excess electrons or holes, pair of electrons with antiparallel spins may travel through the lattice and resonating valence bond state is created. The state of electrons has been presented as follows:

Electrons on the neighbouring site couple into what are called singlet. This means that each of the magnetic moments of the two electrons spend half of its time pointing up and other half pointing down, i.e., they resonate. The two moments, however, conspire to be in opposite directions. If we replace one of the electrons of singlet with a hole, say by substituting an ion of lower valence, the remaining moments of the electrons has nothing to pair with. If we add a further hole, the corresponding two unpaired moments may pair up to form a singlet. Thus, as the holes move from site to site, the resonating magnetic moments constituting the singlet break up and form new singlets. These holes in resonating valence bond state undergo Bose condensation and lead to superconductivity. Hence the RVB state could be considered as a mixture of singlet pairing of electrons in a specific way. It has no obvious long-range order.

Anderson reports that the RVB model predicts or is compatible with several measurable quantities, some of which are: (a) the absence of gaps, (b) the insulating and/or antiferromagnetism of undoped or weakly doped Cu-O compounds, (c) the absence of an isotope effect, low temperature specific heat, and elastic properties dominated by electronic energies, (d) the anomalous temperature dependence of the normal resistivity and the carrier density versus Hall-Seebeck coefficients and (e) the effective mass $m^* = m_e/\delta = 10m_e$, where $\delta$ is doping fraction.

1.5.6 Spin fluctuation mechanism

In view of the existence of strong antiferromagnetic spin fluctuations in the two-dimensional CuO planes of the high-$T_c$ superconductors, a pairing interaction on the basis of the exchange of spin fluctuations instead of phonons has been proposed by several investigators. In this model, using a second order perturbation approach, $d$-
wave spin zero pairing is found to be the most stable condensate [Scalapino et al. 87]

A nonperturbative approach to pairing involving 2D-spin correlation is the spin bag scheme. Here one takes into account the spin density wave (SDW) gap, or rather pseudo gap, in the absence of long range spin orders. The spin alignment remains antiferromagnetic inside the bag [Schrieffer et al. 88]. In this model the attractive potential appears to lead to a nodeless gap, that is $s$-wave singlet pairing and potentially a large value of $T_c$.

1.6 Necessity of present work

The discovery of superconductivity in a perovskite oxide BaPb$_{1-x}$Bi$_x$O$_3$ with $T_c \sim 13$ K as well the identification of superconducting state in Ba$_{1-x}$(K,Rb)$_x$BiO$_3$ with a $T_c$ of 30 K, motivates to reveal the nature of attractive pairing mechanism leading to superconducting state in the novel bismuth oxides, which is similar to those of the high temperature La- and Y-based copper oxides. The copper oxide based systems are highly anisotropic in their physical properties due to 2-D character of the conducting copper oxide (CuO$_2$) planes. However, the non-transition metal compound BaPb$_{1-x}$Bi$_x$O$_3$ is isotropic as the oxygen octahedra form a 3-D network. The parent compound La$_2$CuO$_4$ is an antiferromagnetic insulator, instead BaBiO$_3$ is semiconducting with a low density of states at the Fermi level.

The chemical substitution of Pb (K) in place of Bi (Ba) and the doping concentration in La-based cuprous oxides introduces free charge carriers (holes), and the parent lattice is modified. A number of experimental observations on transition temperature ($T_c$), electrical resistivity ($\rho$), optical conductivity ($\sigma$) and magnetic properties in these metal oxides are reported. The properties of these classes of materials exemplify their unusual nature. Experimental studies of copper oxide superconductors exhibit a quasi-2D character of charge carriers suggesting a layered structure for these materials. Correspondingly, these offers a challenge to the key problem that exists for the theoretical understanding of anomalous properties in high-$T_c$ oxides and no systematic efforts have been made, so far.

Motivated from the above mentioned necessity and in view of the earlier experimental and theoretical findings it was thought pertinent to develop an
effective dynamic interaction which incorporates screening of carriers by plasmons and by phonons to discuss the nature of pairing mechanism as well as physical parameters in the superconducting state [Varshney et al. 97b, Varshney et al. 98c, Varshney et al. 98d, Varshney et al. 99c]. The bismuth oxide and cuprate systems are treated as an ionic solid and a model dielectric function is set up which fulfills the appropriate sum rules on the electronic and ionic polarizabilities. The model parameters namely the electron-phonon coupling strength $\lambda$ and the Coulomb repulsive parameter $\mu^*$ are deduced from the interaction potential and finally, the superconducting transition temperature $T_c$, the oxygen isotope effect $\alpha$, energy gap parameter $\beta$ and transport property as resistivity $\rho$ of bismuth and cuprous oxides are evaluated.

The thermodynamical parameters describing the superconducting state parameters i.e. London penetration depth ($\lambda$), coherence length ($\xi$), critical magnetic field ($H_c$) and temperature derivative of upper critical magnetic field are of fundamental importance. These parameters along with anisotropy are derived using electron-energy band structure studies and Fermi-liquid approach with an open Fermi surface. The estimated values of $\lambda$ and $\xi$ from the Fermi-liquid description [Varshney et al. 96a, Varshney et al. 96b] are in close agreement with the magnetization measurements.

The frequency dependence of optical conductivity of optimised doped $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ ($\delta=0.0, T_c = 92\text{K}$) superconductors have been theoretically investigated based on two component (Drude and mid infrared terms) model within the Fermi liquid description [Varshney et al. 98e]. Our approach incorporates the Drude contribution as well as hopping of holes as carriers in the model dielectric function along with the structure factor. It explains the anomalies observed in the optical measurements for the normal state as the frequency dependence of optical conductivity using the Drude term which gives a sharp peak at zero frequency, and a long tail at higher frequencies, i.e. in the infrared region.

The phenomenon of current excited plasma instabilities is studied based on layered electron gas model of quasi two-dimensional planes in anisotropic copper oxide superconductors [Varshney et al. 98f]. A dielectric response function is
developed in two-temperature domains i.e., at low temperature \( T \approx 0 \) K and near the vicinity of \( T_c \). From the present analysis, we find that at low temperature a cold beam type current excited instability is generated, as the scattering effects are absent. This instability might occur due to Cooper pair breaking effects. We find that for these anisotropic cuprate superconductors the \( T_c < \varepsilon_F \) as well as \( T_c < \Delta \), the drift velocity does not exceed the phase velocity and hence the damping will be associated with the single particle absorption in original plasma waves. The present results of superconducting and normal state transport properties in Bismuthates and cuprates are, generally, in good agreement with their experimental data. The results obtained from the present approach for these superconductors seem to be quite useful in many ways to the scientific community.

1.7 **Summary of the present work:**

The subject matter of the present theoretical investigations reported in this thesis, has been organized as follows:

An effective dynamic interaction, which incorporates the screening of charge carriers by optical phonons and by plasmons is developed in chapter 2 for bismuth oxides and for copper oxides in chapter 3 to discuss the nature of pairing mechanism leading to superconducting state and the normal state resistivity. The chapter 4 shows the discussion on the thermodynamical properties describing the superconducting state i.e. London penetration depth (\( \lambda \)), coherence length (\( \xi \)), critical magnetic field (\( H_c \)) and temperature derivative of upper critical magnetic field and their behaviour with temperature. The optical conductivity in Y-Ba-CuO superconductors within the framework of two component model is investigated and discussed in chapter 5. In chapter 6 we examine the phenomenon of current excited plasma instabilities in the layered high-\( T_c \) superconductors as an application. A general discussion and summary along with the conducting remarks have been presented in the last chapter 7.