International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Comparative Studies Between Lattice Dynamical Study And Normal Coordinate Analysis of HTSC $EuBa_2Cu_3O_6$

K. Sonamuthu[1], Geena Vidya. S[2]

J N R Mahavidayalaya, Port Blair, South Andaman, India.744104, Sathyabamal Engineering College, Chennai-600066

ABSTACT

It is generally believed, that is needed to sign post the way to the development of materials with high critical temperature, even to room temperature and above, is the formulation of a proper theoretical understanding of superconductivity in these materials. Many experimental studies suggest an intimate relationship between phonons, and the superconducting transition in the high T_c oxides.For example, Raman frequencies and line widths, elastic constants and thermal conductivity all show changes around T_c. Nevertheless, there is not a well- developed theory to explain how the phonons are related to T_c.. In conventional superconductors, the role of phonons is well established. However, in high T_c superconductors, the role played by phonons is controversial. Even if they do not mediate the pairing mechanism, they are likely to play an important subsidiary role. Hence there is much interest in the phonon structure of these materials.

The normal state and superconducting properties are believed to arise from the strongly correlated motion of the electronic charge carries (electrons or holes) in the CuO_2 planes that essentially define the layered cuprate HTSC. The other cations and oxygen atom in the structure provides structural stability and control the number of charge carries in the CuO_2 planes.

The Raman spectroscopy of HTSC explains that the role played by the phonons in the mechanism of superconductivity in the perovskite family of superconductors is not fully understood although a large series of experimental results has shown considerable coupling of some phonons to electronic excitation in these systems. Optical spectroscopy and especially Raman and Infrared spectroscopy revealed strong direct influences of the changes in the electronic states to the phonon at the center of the Brillouin.

Keywords: Superconducting, Raman spectroscopy, Brillouin, Three Body Force Shell Model, Normal Co-Ordinate Analysis, Lattice Dynamical Calculation, PED, etc.,

1. Introduction

The discovery of the high super conducting transition of the La-Ba-Cu-O system by Bednorz and Muller has caused unprescedented world wide activities in the search and characterization of high T_c superconductor is of importance, not only for the overall physical characterization of the role played by the phonons in the superconducting phenomenon.

Born-Killermann theory of ionic crystals explains the temperature variation of specific heats of many alkali halides reasonable well, but falls to describe the details of vibrational spectra. The three body

force shell model (TSM) developed from Verma and Singh [1] was reviewed by Cochran on the simple consideration that the electron shell is deformation. This deformation give rise to the three body interactions and accounts for the observed Cauchy discrepancy. The displacement on the other hand introduces the electronic polarization and accounts for the dielectric properties. Veram and Agarwal [2] redefined the shell and core charges suitably and hence the basic equation of the model have been modified. Woods et al. [3] has shown that TSM is equivalent to the breathing shell model (BSM).

2. Lattice Dynamics of HTSC $EuBa_2Cu_3O_6$ based on Three Body Force Shell Model

The new high T_c materials contain numerous particles in the unit cell. Thus, in a classical approach to lattice dynamics, a large number of unknown force constants has to be specified. Much attention has been paid, from several points of view, to copper-oxide-based high T_c Superconductors with the formula **$EuBa_2Cu_3O_6$** discovered by Cava et al. [4-12].

The study of the lattice dynamics of the high T_c Superconductors is of importance , not only for the overall physical characterization of these compounds, but also for an assessment of the role played by the phonons in the superconducting phenomenon. Our approach is based on the use of long -range Coulomb potentials and short-range repulsive Born Mayer potentials, as well as ionic polarizabilities, in the framework of the shell model.

The calculation of lattice dynamical vibration frequencies of $Tl_2Ba_2Cu_1O_6$ system is performed by thee-body force shell model (TSM) calculations. In the shell model calculation the equations of the motion for the code coordinate U and the shell coordinate W are expressed as [13] follows:

$-M\omega^2U = (R + ZC'Z)U + (T + ZC'Z)W$

$0 = (T - YC'Z)U + (S + K + YC'Y)W$

with $ZC'Z = Z[Z + 12 f(a)]C + V$ where M, Z and Y are diagonal matrices representing the mass ionic charge on the shell, R, S, T are matrices specifying short-range core-core, shell-shell and core-shell interactions respectively, V is the matrix describing the three-body overlap interactions and f(a) is related to overlap integrals of electron wave function. U and W are the vectors describing the ionic displacements and deformations respectively.

In the earlier approaches the R, S and T elements were considered to be equal to one another. In the present investigation, we have started with n approach such that $R \neq S \neq T$ [10]. That is the various interactions between the ions are treated in a more general way without making them numerically equal. The dynamical matrix of the model consists of long-range Coulomb and three-body interactions and the short range overlap repulsions. The off-diagonal elements of this matrix along the symmetry directions chain a completely new term having a significant contribution for unequal R, S and T.

The lattice dynamical calculation of high-temperature superconductors is explained using an inter ionic potential consisting of long-range Coulomb part and a short range Potential of Born-Mayer form [14-15].

$V_{ij} = a_{ij} \exp(-b_{ij} . r)$

Where i, j label the ions and r is their separation. The parameters a_{ij} and b_{ij} are the pair potentials and the parameters Y and K determine the electronic polarizabilities. The parameters used in the present calculations are given in Table 1. Phonon frequencies are calculated using the force constants derived from the inter ionic potential. Following Leaner et al [14] inter-ionic pair potentials for short-rang interactions can be transferred from one structure to another in similar environments. The force constants evaluated by this method are in good agreement with the evaluated values [15-18]

3. Normal Co-Ordinate Analysis Of Superconductor $EuBa_2Cu_3O_6$.

A molecule possesses three types of internal energy. These are electronic, vibrational, and rotational energies. Every molecule, at all temperatures, is continually executing vibrational motions. The complex, random, and seemingly a periodic internal motions of a vibrating molecule are the result of the superposition of a number of relatively simple vibratory motions known as the normal vibrations or normal modes of vibration of the molecule. Each of these has its own fixed frequency. Naturally, when many of them are superposed, the resulting motion must also be periodic, but it may have a period so long as to be difficult to discern the generalized co-ordinates, each one of them executing oscillations of one single frequency, are called normal co-ordinates.

4. Normal Co-ordinate Analysis of The Zero Wave-Vector Vibration of $EuBa_2Cu_3O_6$

The study of lattice vibrations and the free carriers is important for the understanding of the physical nature of high temperature superconductors. Raman and far-infrared studies of these superconductors have contributed significantly to the understanding of new class of superconductors. Cardona and coworkers [19] studied the infrared and Raman spectra of the super conducting cuparate perovskites $MBaCu_2O_2$ (M = Nd, Er, Dy, Tm and Eu) and reported the possible origins of phonon softening and the systematic variation of phonon frequencies with the ionic radius. Here an attempt has been made to perform the normal coordinate analysis for the phonon frequencies and the form of the zero wave vector vibrations for the **$EuBa_2Cu_3O_6$** superconductors.

The high Tc superconductor **$EuBa_2Cu_3O_6$** System crystallizes in the body-centered tetragonal (bct) system, which belongs to the space group 14/mmm (D^{17}_{4h}) The body-centered tetragonal (bct) unit cell of **$EuBa_2Cu_3O_6$** and the numbering of the atoms are shown in Fig.1. The 12 atoms of the unit cell yield a total of 24 optical vibrational modes. All the above calculations are made at q=0. Once of A_{2u} and E_u modes corresponds to acoustic vibrations with frequency $\omega = O$. These normal modes are distributed as follows.

$A_{1g} + E_g + A_{2u} + E_u$ □ from the motion of Eu atoms

$A_{1g} + E_g + A_{2u} + E_u$ □ from the motion of 2 Ba atoms

$A_{2u} + E_u$ □ from the motion Cu (1) atoms

$E_g + A_{2u} + B_{2u} + 2E_u$ □ from the motion O (1) atoms alone c-axis

$A_{1g} + E_g + A_{2u} + E_u$ □ from the motion O (2) atoms alone b-axis

$A_{1g} + E_g + A_{2u} + E_u$ □ from the motion O (3) atoms alone a-axis

Subtracting the translation modes $A_{2u} + B_{2u} + E_u$ the q = 0 optical modes involved in an irreducible representation are as follows.

$$\Gamma_{opt} = 4A_{1g} + B_{1g} + 5E_g + 5A_{2u} + B_{2u} + 6E_u$$

The species belonging to A_{1g} and E_g Raman active modes whereas $A_{2u}B_u$ are infrared active modes. The A_{2u} and A_{1g} modes involve displacement along crystallographic c-axis, the B_{2u} and E_g modes along the b-axis and Eu modes along the a-axis. The normal coordinate calculation was performed using the programs GMAT and FPERT given by Fuhrer et al [20]. The general agreement between the evaluated and observed normal frequencies of **$EuBa_2Cu_3O_6$** is good. The calculated force constants using the above programs are given in Table 2. It is interesting to note that the evaluated frequencies given in Table 3, agree favourably with the experiment values.

To check whether the chosen set of vibrational frequencies makes the maximum contribution to the potential energy associated with the normal coordinate frequencies of the super conducting material, the potential energy distributions was calculated using the equation.

$PED = (F_{ij} L^2_{ik})/ \lambda_k$

Where PED is the combination of the i-th symmetry coordinate to the potential energy of the vibration whose frequency is $V_k F_{ij}$ are potential constants, L_{ik} are L matrix elements and $\lambda_k = 4\pi^2 C^2 \upsilon^2_k$.

5. Result and Discussion

5.1 Lattice Dynamical Calculation HTSC $EuBa_2Cu_3O_6$ using Three Body Force Shell Model

The Lattice Dynamical calculations based on modified TSM reproduce the observed frequencies of Raman and infrared active modes reasonable which are given in table 3. The calculated frequencies are in good agreement with the available experimental values. The lowest calculated Raman active A_{1g} mode frequency at 118 cm^{-1} is due to the vibration of Eu atoms and this agrees very well with the experimental frequency at 120 cm^{-1}. Similarly the calculated Raman frequency is A_{1g} symmetry at 184 cm^{-1} and 431cm^{-1} are due to the vibration of Ba and O(2) atoms respectively and the observed frequencies at 185 and 435 cm^{-1} agrees very well with the calculated frequency. The highest calculated Raman frequency 462 cm^{-1} in A_{1g} symmetry is due to the vibration of O(3) atoms which also agrees very well with the observed frequency at 463 cm^{-1}

Further we have investigated the following Zone centre frequencies in the Raman active mode in the symmetry at 80, 160and 416 cm^{-1} are due to the vibration of Ba, Cu and O(1) atoms respectively. The maximum vibrational frequency in E_g symmetry is 515 cm^{-1} which is due to the vibration of O(2) atoms. The calculated infrared frequency is A_{2u} symmetry at 136 cm^{-1} is due to the vibration of Cu(1), Ba and Tl atom whereas the atom Tl vibrates at 180^0 out of phase to Ba and Cu(1) atom and the observed frequency 138 cm^{-1} agrees very well with the experimental values. The infrared photon frequency at 162Cm^{-1} is due to the vibration of Ba and Cu (1) atoms and its experimental value is 163 cm^{-1}. The evaluated photon frequency at 173 cm^{-1} is due to the vibration of Cu (1) and O(1) atoms and its experimental values is 173cm^{-1}. The evaluated infrared frequency at 339 cm^{-1} is due to the vibration of O(2), O(1) and Cu atoms in which O(1) atom vibrates at 180^0 out of phase to O(2) and Cu atoms. The highest evaluated phonon frequency in A_{2u} symmetry is 497 cm^{-1} which is due to the vibration of O(3) atom and its observed frequency at 496 cm^{-1} in A_{2u} symmetry modes agrees very well with each other.

The evaluated phonon frequencyin B_{2u} symmetry mode at 126cm^{-1} is due to the vibration of O(1) atoms. The Calculated infrared phonon frequency at 103cm^{-1} in E_u symmetry is due to the vibration of Ba and Cu(1) atoms and its experimental frequency at 104 cm^{-1} agrees very well with the evaluated values. The infrared phonon frequency at 134cm^{-1} is due to the vibration of Cu(1) and Ba atoms and its observed frequency 133 cm^{-1} agrees very well with the calculated frequency. The infrared phonon frequency at 213 cm^{-1} is due to the vibration of O(1) atom which performs bending bond vibrations and its observed frequency 213 cm^{-1} agrees very well with the calculated frequency. The highest infrared frequency 514 cm^{-1} is due to stretching of O(1) atoms and its experimental values 513 cm^{-1} agrees very well with observed frequency.

5.2 Normal coordinate analysis of HTSC $EuBa_2Cu_3O_6$

The G-matrix elements have been calculated from the equilibrium geometry. The initial force constants were taken from the related molecules. The final sets of potential constants provide the stability of the

crystal in relation to all vibrational modes. The vibrational frequencies and potential energy distribution values are presented in this work. The potential energy distribution indicates the contribution of an individual force constant to the vibrational energy of normal modes. It clearly indicates that there is mixing of the internal displacement coordinates.

The evaluated frequencies using the normal coordinate analysis method listed in table 3. agrees favourably with the calculated lattice dynamical frequencies and observed experimental frequencies. The calculated Raman phonon frequency at $120cm^{-1}$ inA_{1g} symmetry agrees very well with the observed frequency at $120cm^{-1}$. This is the lowest phonon frequency due to the vibration of Eu atom, and is due to the bending vibration of O(2)-Cu-O(3),which is confirmed by the potential energy distribution calculation. The calculated Raman phonon frequencies at $185cm^{-1}$, $437cm^{-1}$ are due to the vibration of Cu and O(2) atoms,both the oscillation are due to the bending vibrations. The highest frequency in this mode is 453 cm^{-1} is due to the vibration of O(2). Both the frequencies agrees very well with the observed frequencies at $463cm^{-1}$.

The calculated Raman phonon frequencies in E_g symmetry at $86m^{-1}$,$420cm^{-1}$ and $437cm^{-1}$ are due the vibration of Eu ,Cu and O(2) atoms respectively. All these vibrations are bending vibration which is confirmed by the potential energy distribution calculation. The highest calculated phonon frequency at $5516cm^{-1}$ is due to the vibration of (O2)atom and it is due to stretched vibration.

The calculated infra red phonon frequencies in A_{2u} symmetry at $136cm^{-1}$, $169cm^{-1}$ are due to the vibration of Cu(1) and O(1) atoms and due to the stretched vibration. The calculated phonon frequencies and observed frequencies agrees very well with each other. The infrared phonon frequencies at $173cm^{-1}$, $339cm^{-1}$ and $498cm^{-1}$ are due to the vibration of Cu(1),O(2) and O(3) atoms which is due to bending vibration. The frequency at $498cm^{-1}$ in this symmetry is due to the bending vibration of O(2)-Ca-O(1).

The calculated infra red phonon frequencies in E_u mode at $103cm^{-1}$ is due to the vibration of stretched vibration of Ba-O(1).The calculated highest infrared phonon frequency at 551 cm^{-1} is due to the vibration of O(3) atom, which agrees very well with the observed phonon frequency at $513cm^{-1}$ is confirmed by the Potential Energy Distribution calculation.

6. Comparative Studies Between Lattice Dynamical Study And Normal Coordinate Analysis Of HTSC $EuBa_2Cu_3O_6$

The comparative study between Lattice dynamics and normal coordinate analysis of high temperature superconductors **$EuBa_2Cu_3O_6$**. In the present investigation the lattice dynamical calculations and normal coordinate analysis yield same phonon frequency a bridge between Solid State Physics and Spectroscopy to understand the mechanism of superconductivity. Raman and infrared studies of these HTSC have contributed significantly to their understanding. The assignment of the spectral features to specific lattice vibrations would be an important step in understanding their role in superconductivity.

The lattice dynamics method is suited to determine the phonon frequencies in the proximity of the Brillouin zone centre only. But , the force constants obtained from that analysis do not provide a stable dynamics throughout the Brillouin zone. However, it is indispensable to have a precise knowledge of the zone –boundary phonons to investigate the contribution of electron-phonon coupling to T_c which can be achieved by neutron scattering techniques. The most commonly employed model is the valence force field model for computing phonon frequencies based on stretching bond and bending bond coordinates. Such models have the advantage of being well adopted to describe a covalent bonding but ignored the long –range Coulomb forces and wave vector dependence of the phonon spectrum. This work

considered only the q=o modes and the number of model parameters exceeded the number of experimental data. The rigid ion model on the other hand , considers both the short-range repulsive interactions and the long range Coulomb interaction among various rigid ions in the crystal. The lattice dynamics of high temperature of high temperature superconductor have been performed using rigid ion model. The modified three body shell model adopted in the lattice dynamical study gives favourable phonon frequencies.

The lattice dynamical calculation based on modified TSM reproduce the observed frequencies of Raman and infrared active modes reasonably which are given in table 3. along with calculated normal coordinate analysis frequencies and the observed frequencies.

The calculated Raman phonon frequency at 118cm^{-1} in A_{1g} symmetry is due to the vibration of Eu atom which agrees very well with the normal coordinate analysis's frequency at 120cm^{-1} and it is due to the bending vibration of O(2)–Cu-O(3) which is confirmed by the potential energy distribution calculation. The highest frequency in this symmetry in lattice dynamical is 462cm^{-1} ,which is equal to 463cm^{-1} in normal coordinate analysis which is due to the vibration of O(2) and this phonon frequency is due to the stretched vibration of O(2).

The phonon frequency at 363cm^{-1} in lattice dynamics is more or less equal to the phonon frequency obtained by the normal coordinate analysis. This phonon frequency is due to the bending vibration. The phonon frequency 416cm^{-1} and 4371cm^{-1} E_g symmetry in lattice dynamical calculation agrees very well with the frequencies obtained by the normal coordinate analysis at 416cm^{-1} and 437cm^{-1} respectively. Both these frequency are obtained in the bending vibration mode.

The minimum infrared phonon frequency in A_{2u} at 136 cm^{-1} in lattice dynamical calculation is due to the vibration of Ba atom which agrees very well with the frequency obtained by the normal coordinate analysis at 138cm^{-1} which is performed by stretching vibration and it is confirmed by the potential energy distribution calculation. The maximum frequency in this symmetry is 497cm^{-1} in lattice dynamics which agrees very well with the frequency obtained by the normal coordinate analysis at 4961cm^{-1} is due to the stretched vibration of O(3), which is confirmed by PED calculation.

The phonon frequency in lattice dynamics at 372cm^{-1}in E_u symmetry is due to the vibration of O(1) atom agrees very well with the frequency obtained by the normal coordinate analysis at 373cm^{-1} which is due to bending vibration. Finally, the phonon frequency in this symmetry at 514cm^{-1} in lattice dynamics agrees with the frequencies obtained by normal coordinate analysis at 513cm^{-1} is due to the stretched vibration of O(3) atoms which is confirmed by the PED calculation.

7. Conclusion

In this work, two different methods viz, lattice dynamical study and normal coordinate analysis yielded the same phonon frequency for high temperature superconductor **$EuBa_2Cu_3O_6$**.. It is also seen from the tables , that the agreement between the calculated and observed frequencies wherever available are very good for the systems under consideration.

Therefore, it is concluded that metal - oxide (Cu-O) plays an important role for the occurrence of superconductivity. The Raman scattering has provided direct evidence for strong electron –phonon interaction in the high T_c superconducting oxides. The vibrational frequencies calculated by the methods of Lattice Dynamics and Normal Coordinate Analysis are compared and they appear to be in good agreement, which is confirmed by the Potential Energy Distribution calculation..

8. Reference

1. Inorganic Infrared and Ramnd Spectra by S.D.Rose , McGraw-Hill Book Company , England , 1972.
2. Elements of Spectroscopy by S.L.Gupta, V. Kumar, R.C. Sharma, Pragati Praksahan, India , 1983.
3. Infrared Spectroscopy by R.T. Conley Allyn & Bacon Ltd., 1966.
4. Molecular Spectra and Molecular structure : Vol.2 , Infra-red and Raman Spectra of poly atomic molecules, G.Herzberg, Van Nostrand, USA, 1945.
5. Infrared spectra of inorganic and co-ordination compounds , K. Nakamotao. John Wiley, New York, 1st edition 1963.
6. Fundametnals of Molecular Spectroscopy by C.N Banwell, Tata McGraw-Hill Book company, New Delhi, Second Edition 1975.
7. Introduction to infra-red and Raman Spectroscopy , S.E. Wiberley, N.B Colthup and L.H.Daly Academic press (New York) , 1st edition 1964.
8. Theory of Molecular Spectra , W.A.Bingal, Wiley , 1969.
9. Chemical Applications of Group Theory , F. Albert Cotton , Wiley Eastern Ltd., Second Edition 1971.
10. Vibration spectra and structure of polyatomic molecules , T.Y.Wu, National University of peking , Kun-ming China , 1939.
11. J.C. Decius , J.Chem. Phy. 22, 1941 (1954)
12. Molecular vibration by E.Bright Wilson Jr., J.C. Decius and P.C. Cross , MacGraw-Hill Book Company, New York , First Edition (1955)
13. E.B.Wilson, J.Chem. Phys. 7, 1047 (1939).
14. Group Theory applications to molecular vibrations by P.G.Puranik , S.Chand & Company LTd., First Edition (1979).
15. Y.Marino and K.Kuchitsu, J Che. Phy. 20 1809 (1952).
16. E.Bright Wilson , J.Chem. Phy. 9 76 (1941).
17. Molecular Symmetry , D. Schonland, D Van Nostrand, London, McGRaw - Hill Book Company, 1st Edition (1965).
18. S.Mohan and A.Sudha , Pramana J. Phys. 37, 4, 327, (1991).
19. C.Thomsen, M.Cardona, W.Kress, R.Liu. L. Genzel, M Bauer, E.Schonherr and U Schroder, Solid State Commun. 65 (1983) 1139.
20. G . Burns, F.H Dalcol, F Holtzberg and D.L. Kaiser, Solid State Commun. 66 (1988) 217.

Table: 1 Force constants for $EuBa_2Cu_3O_6$

Parameters of the model: a, b are Born-Mayer constants: Z,Y,K, ionic charge, shell charge and on-site core-shell force constant of the ion, V_a is the volume of the unit cell.

Interaction	a (eV)	b ($Å^{-1}$)
Eu-O (Same plane)	3000	2.80
Eu-O (adj plane)	3000	3.55
Ba-O	2.90	3220
Cu-O	1260	3.35
O-O	1000	3.00

Ion	Z(|e|)	(|e|)	k(e^2|Va)
Eu	2.70	2.00	1000
Ba	2.00	2.32	207
Cu	2.00	3.22	1248
O (Cu-O) Plane	-1.90	-2.70	310
O (Cu-O) Plane	-1.93	-2.70	210
O(Ba-O) Plane	-1.93	-2.70	310 (Kוו) 2100 (K_)

Table: 2

Force constants for **$EuBa_2Cu_3O_6$** (in units of 10^2 Nm^{-1} (stretching) and 10^{-18} Nm rad^{-2} (bending))

Potential constant	bond type	distance (Å)	initial value
f_b	Ba-O(1)	2.798	0.75
f_c	Ba-O(2)	2.819	1.10
f_d	Ba-O(3)	2.851	0.81
f_e	Eu-O(1)	2.003	0.30
f_g	Eu-O(2)	2.097	0.30
f_h	Eu-O(3)	3.108	0.61
f_k	Eu-O(3)	2.402	0.48
f_l	Cu-O(1)	1.932	0.145
f_m	Cu-O(2)	2.648	1.65
f_n	Eu-O(3)-Eu	--	0.31
f_p	O(1)-Cu-O(1)	--	0.25
f_a	Eu-O(2)-Ba	--	0.46
f_β	O(2)-Eu-O(3)	--	0.80

Table.3 Calculated Phonon frequencies of $EuBa_2Cu_3O_6$

(*Values in the Parentheses are experiment frequencies***)**

Symmetry species	Frequency(cm^{-1}) Using Lattice Dynamics	Using Normal Coordinate analysis	Potential Energy Distribution(%)
A_{1g} (Raman)	118(120)	120	f_b (60)f_d(20)f_k(10)
	184(185)	185	f_i (70)f_d(11)f_p(10)
	431(435)	437	f_e (55)f_a(31)
	462(463)	463	f_a (58)fe(30)f_m(11)
$B1_g$	363	362	F_l (68)fd(14)f_m(10)

E_g	80(85)	86	f_c (61)f_e(11)f_b(15)
	160(165)	164	f_m (70) f_i(21)
	416(416)	420	f_a (45)f_g(31)f_n(20)
	437(437)	437	f_n (64)f_h(21)f_m(15)
	515(513)	516	F_k(66)fl(20)f_m(15)
A_{2u} (IR)	136(138)	136	f_n (70)f_a(12)
	162(163)	169	f_m (65)f_a(19)f_d(15)
	173(173)	173	f_p (59)f_n(30)
	339(340)	339	f_p (62)F_b(19)f_n(15)
	497(496)	498	f_a (60)f_e(21)f_m(16)
B_{2u}	126(120)	126	f_p (51)f_n(24)f_e(16)
Eu	103(104)	103	f_b (70)f_e(14)
	134(133)	132	f_a (65)f_e(22)
	213(213)	214	f_a (49) f_d (17) f_e(21)
	372(372)	373	f_a (60)f_b(22)f_k(11)
	415(411)	418	f_b (66) f_p (21)
	514(513)	515	f_n (62)f_a(20)

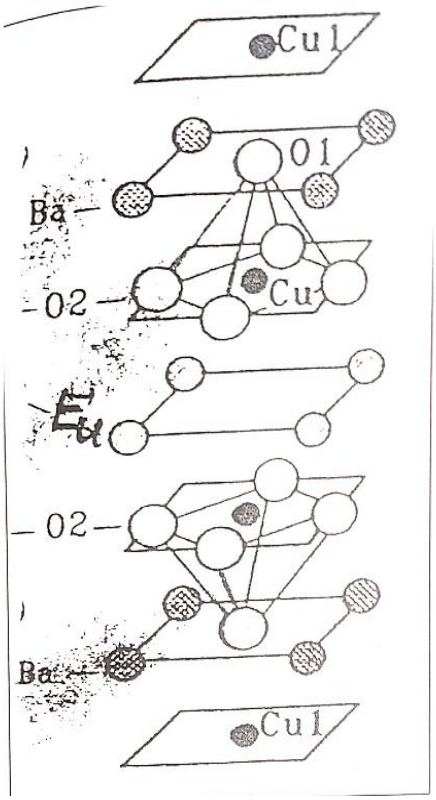

Fig 1: Unit Structure of HTSC $EuBa_2Cu_3O_6$