M. Sc Final (IV Semester)

Course: Paper 4104 (Section A), Inorganic Materials

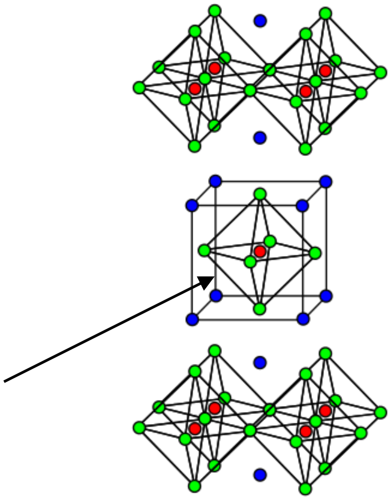
Course Instructor: Professor S. Uma

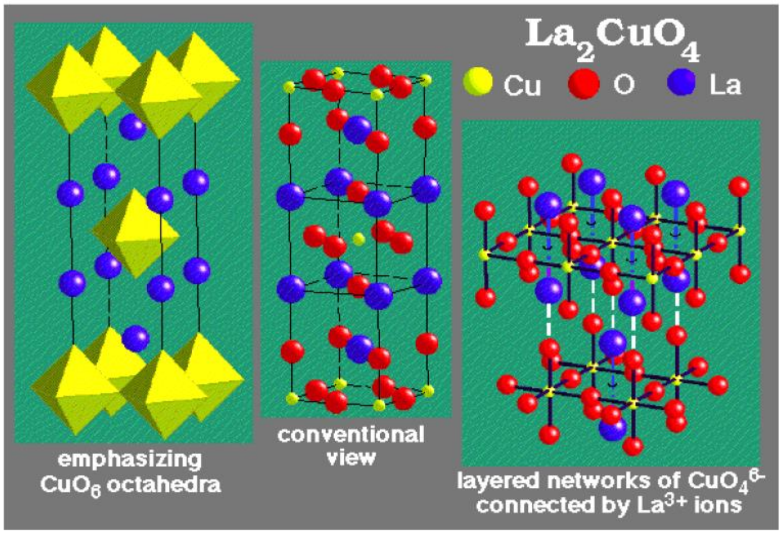
Topic: High temperature superconductors

Content: Introduction to superconductors, Type I, Type II, Meissner effect have been covered in the class. Other examples included are the La_2CuO_4 and $YBa_2Cu_3O_7$ (1-2-3) based superconductors including their structures and few applications of superconductors.

Crystal structures of high-temperature ceramic superconductors

- The structure of high-T_c copper oxide or cuprate superconductors are often closely related to **perovskite** structure, and the structure of these compounds has been described as a distorted, oxygen deficient multi-layered perovskite structure.
- One of common features of the crystal structure of oxide superconductors is an alternating multi-layer of CuO_2 planes with superconductivity taking place between these layers. The more layers of CuO_2 , the higher T_c.
- This structure causes a large *anisotropy* in normal conducting and superconducting properties, since electrical currents are carried by **holes induced in the oxygen sites of the CuO_2 sheets**. The electrical conduction is highly anisotropic, with a much higher conductivity parallel to the CuO_2 plane than in the perpendicular direction.
- Generally, Critical temperatures depend on the chemical compositions, cations substitutions and oxygen content.





The arrow points out to the perovskite ABO_3 (A is a larger cation such as K^+, Sr^{2+}, or La^{3+}, and B is a smaller transition metal ion) from which the La_2CuO_4 structure has been built. A is usually 12 coordinated and B is six coordinated and forms corner shared octahedral to form the 3-D structure.

When additional rock salt AF (or AO) is inserted, the result is K_2NiF_4 ($KNiF_3$ perovskite plus KF) and La_2CuO_4 belongs to this class of oxides. The coordination of K (La) changes to nine. The structure can also be viewed as arranging ABO_3 units using two ABO_3 (with A in the origin) units after slicing of the top layers in both and intercepted by ABO_3 with B cations in the origin. The conventional view in the above figure is helpful understand this description.

The substitution of 0.15 Sr^{2+} (or Ba^{2+}) for La^{3+} in La_2CuO_4 forces the oxidation of Cu^{2+} (d^9) to Cu^{3+} (d^8) (or holes) resulting in p-type superconducting oxide with T_c of 35K and the T_c varies with the amount of the dopant ions ($La_{2-x}A_xCuO_4$; A = Ca, Sr, Ba etc).

The parent La_2CuO_4 is antiferromagnetic insulator and by p-type doping the oxide is made as superconducting.

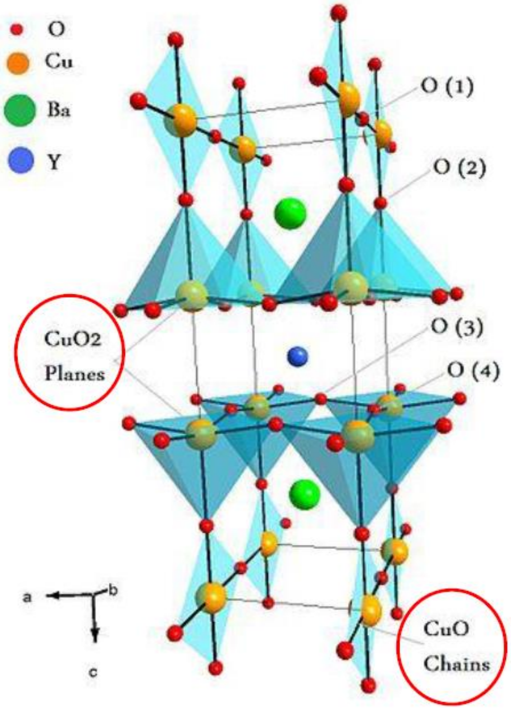
Next is the 1-2-3 superconductor, $Y_1Ba_2Cu_3O_{7-x}$ (structure shown below) oxide with T_c = 90K discovered in 1987. One of the key features of the unit cell of $YBa_2Cu_3O_{7-x}$ is the presence of two layers of CuO_2.

The structure can be seen as derived from perovskite as triple perovskite blocks. While doing so, Y has 8 coordination, Ba has 12 coordination and copper coordination varies depending upon the oxygen content.

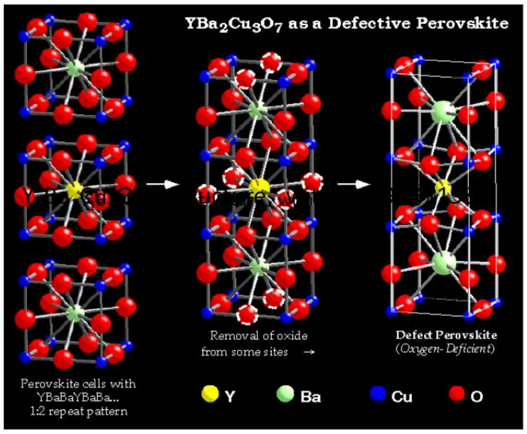
The role of the Y plane is to serve as a spacer between two CuO2 planes. In YBCO, the CuO chains are known to play an important role for superconductivity. Tc is maximal near 92 K when $x \approx 0.15$ and the structure is orthorhombic.

Superconductivity disappears at $x \approx 0.6$, where the structural transformation of YBCO occurs from orthorhombic to tetragonal.

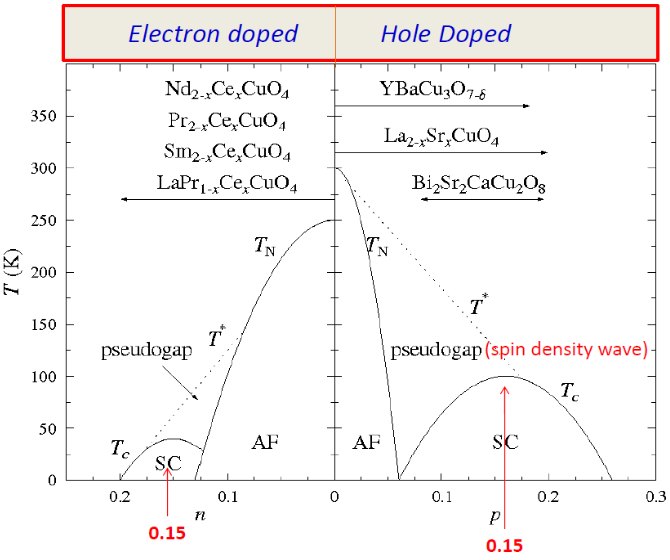
The unique feature is copper changes the coordination along with its change in oxidation states. Cu^{1+} (d^{10}) is linear in $YBa_2Cu_3O_6$ (AF insulator, parent). Both Cu^{2+} (d^9, square pyramid) and Cu^{3+} (d^8, square planar) are present in the oxidized forms when oxygen content is increased from 6.0.



$Y_1Ba_2Cu_3O_{7-x}$ Structure



n-type superconductors are also known. The example is Nd_2CuO_4, where in Nd^{3+} is doped with Ce^{4+} reducing Cu^{2+} to Cu^{1+}. The variation of with dopant concentration is shown (along with other examples) in the figure.



APPLICATIONS OF HIGH T_c SUPERCONDUCTORS

Due to some characteristics of superconductivity i.e. the zero resistance, Meissner effect and Josephson Effect, this can be exploited for applications of these materials. There are many more application of superconductors but out of these, here we are presenting very few. New superconducting magnets could be made much smaller than a resistive magnet, because the windings could carry large currents with no energy loss.

Some applications of high temperature superconductors include; medical imaging systems, superconducting quantum interference devices (SQUIDS), analog signal processing devices, infrared sensors, magnetic shielding devices, and microwave devices, power transmission, superconducting magnets in generators, energy storage devices, particle accelerators, levitated vehicle transportation, rotating machinery, and magnetic separators will become more practical.

The ability of superconductors to conduct electricity with zero resistance can be exploited in the use of electrical transmission lines. The field of electronics holds great promise for practical applications of superconductors. The use of new superconductive films may result in more densely packed chips which transmit information more rapidly by several orders of magnitude. By using superconducting magnets, the prototype levitated trains have been constructed in Japan.