TOPIC: SUPERCONDUCTIVITY

Devansh Dayal

LS-102/Summer 2022/Prof. Doros Petasis

Introduction

Superconductivity is a phenomenon observed in several metals and ceramic materials. When these materials are cooled to temperatures ranging from near absolute zero to liquid nitrogen temperatures (77 K, -196 C), their electrical resistance drops with a jump down to zero. The temperature at which electrical resistance is zero is called the critical temperature (T_c).

When Superconductors, are cooled below the critical temperature, they expel magnetic field and do not allow the magnetic field to penetrate inside them. This phenomenon in superconductors is called **Meissner effect.**

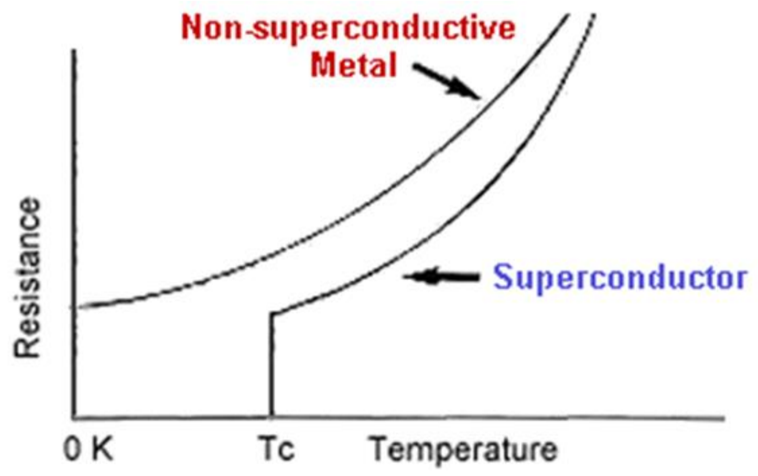

Figure .1. Relation between resistance & temperature of a regular conductor and a superconductor.

Importance of Superconductivity

Superconductivity is not only fascinating, it is also incredibly useful. Superconductors are already used in applications as diverse as seeing inside the human body and discovering the origin of mass. As important as these achievements are, their promise for future revolutionary technologies may be even greater.

Conventional Superconductivity: (BCS theory)

A theory of superconductivity formulated by John Bardeen, Leon Cooper, and Robert Schrieffer. It explains the phenomenon in which a current of electron pairs flows without resistance in certain materials at low temperatures. This can happen, so the theory says, when a single negatively charged electron slightly distorts the lattice of atoms in the superconductor, drawing toward it a small excess of positive charge. This excess, in turn, attracts a second electron. It is this weak, indirect attraction that binds the electrons together, into a Cooper pair.

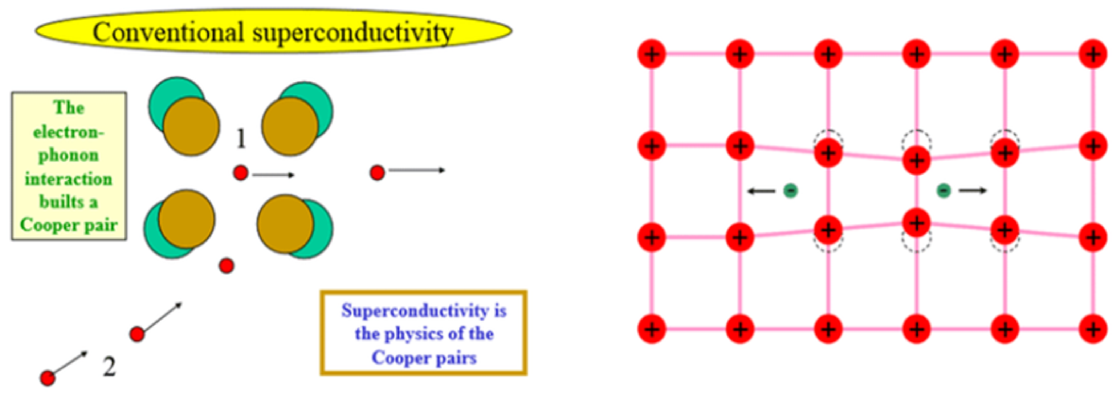

Figure 2. The formation of a cooper pair: A passing electron attracts the positive charged ions of the lattice, causing a slight ripple in its wake. Another electron passing in the opposite direction is attracted to that displacement.

History of Superconductivity:

The attainment of liquid helium temperatures opened a new regime of low temperatures and it was discovered by K. Onnes in 1911, while investigating the electrical properties of frozen mercury when the electrical resistance of mercury completely disappeared on approaching 4.2 K.

High Temperature Superconductivity

High-temperature superconductivity, the ability of certain materials to conduct electricity with zero electrical resistance at temperatures above the boiling point of liquid nitrogen (77 K, -196 C), was unexpectedly discovered in copper oxide (cuprate) materials in 1987. High-temperature superconductivity could revolutionize technologies ranging from magnetically-levitated trains to electrical power transmission.

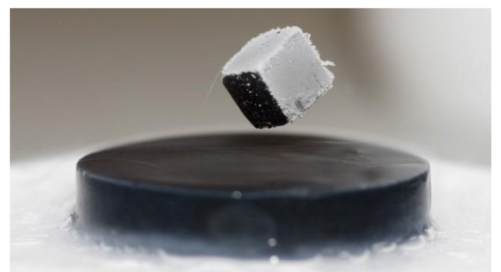

Figure 3. A sample of (BSCCO) which currently is one of the most practical HTS superconductors.

Structure of High Temperature Superconductors:

These compounds are ceramic materials having crystal structures containing layers of copper-oxide. Cuprate superconductors are generally considered to be quasi-two-dimensional materials with their superconducting properties determined by electrons moving within weakly coupled copper-oxide layers. Neighboring lays containing ions such as lanthanum, barium, strontium, or other atoms act to stabilize the structure and hole electrons onto the copper-oxide layers.

Properties of High Temperature Superconductors:

1. Critical temperature/Transition Temperature:

- The temperature below which the material changes from conductors to superconductors is called critical or transition temperature

2. Zero Electric Resistance:

- In the superconducting state, the material has zero resistance. When the temperature of the material is reduced below the critical temperature, the resistance suddenly drops to zero. Eg- Mercury is a superconductor that shows zero resistance below 4 K.

3. Expulsion of Magnetic Field:

- Below the critical temperature, superconductors do not allow the magnetic field to penetrate inside it. This phenomenon is also known as the Meissner Effect as aforementioned.

4. Critical Magnetic Field:

The certain value of the magnetic field beyond which the superconductors return to conducting state is called the critical magnetic field. The value of the critical magnetic field is inversely proportional to the temperature. As the temperature increases, the value of the critical magnetic field decreases.

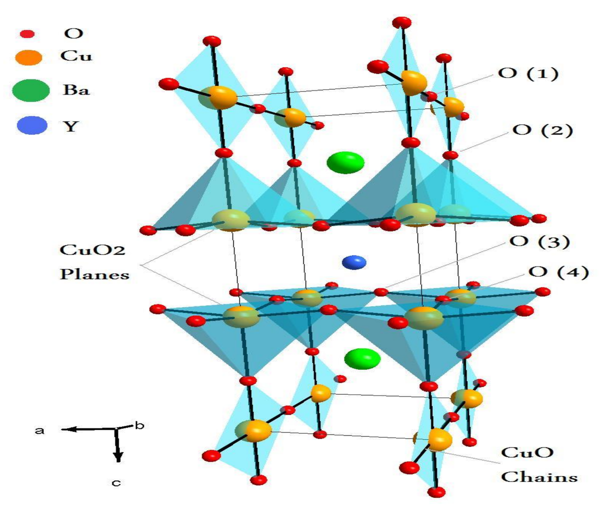

Figure 4. Unit cell for the cuprate of Barium and (YBCO)

Applications of Superconductivity in MRIs

Magnetic Resonance Imaging (MRI), a powerful medical diagnostic tool, is the largest commercial application of superconductivity. The superconducting magnet is the largest and most expensive component of an MRI system. The progress in MRIs is strongly linked to the creation of new devices with always stronger magnetic fields. The main magnetic field is generated by a large superconducting electromagnet in which the electric current flows. The weak resistance of superconductors allows very strong currents to flow with no heating in the material, and hence enables to get very high field values of several teslas. Such field intensities could not be obtained with a copper electromagnet because the high resistance of the conductor would cause, when strong currents flow, Joule effect losses (thermal dissipation) so strong the coil would melt.Fif

Figure 5 : MRI machine

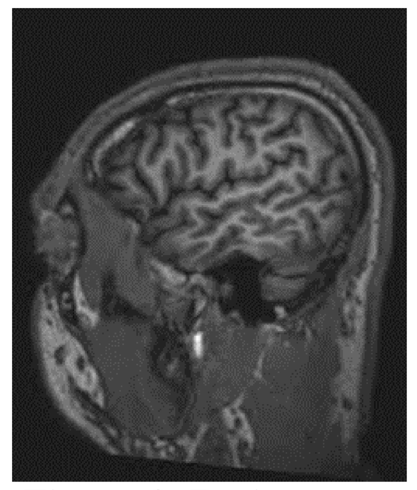

Figure 6: Brain scan with the help of magnetic imaging

Conclusion:

Why do Superconductors need to be cooled

In superconductivity, pairs of electrons bind to each because of the way they interact with the material as a whole. This bonding allows the electron pairs to act like bosons and spread out and overlap in coherent wave states. If a superconductor is too hot, the electrons are jiggling around too violently to maintain electron-electron bonds. Since the bonding between electrons is so weak, you have to have a very low temperature to avoid breaking the bonds. By making the material cold there is less energy to knock the electrons around, so their path can be more direct, and they experience less resistance.

Figure 7: Liquid Nitrogen: One of the simplest coolants in cryogenics.

References

1. A.K. Saxena, *High-temperature superconductors*, Heidelberg, Springer, 2010.

2. I. A. Parinov, *Microstructure and properties of high temperature superconductors with 44 tables*, Berlin Heidelberg New York, Springer, 2007

3. V. L. Ginzburg, "High-temperature superconductivity (history and general review)," Soviet Physics Uspekhi, vol. 34, no. 4, 1991, pp. 283–288.

4. "Superconductors Enable Lower Cost MRI Systems | NASA Spinoff," spinoff.nasa.gov.