What's Super About Superconductors?

Owen Bell[1], Akshay Kapur[1], Jermy Scarpetta[1], Suvan Sunkavalli[1], Viknesh Venkatachalam[1], Caolan John[2]

[1]*Bellaire High School*, [2]*Massachusetts Institute of Technology*

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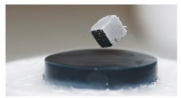
References:

1. Wirfs-Brock, Jordan. "Lost In Transmission: How Much Electricity Disappears Between A Power Plant And Your Plug?" Inside Energy, 6 November 2015, https://insideenergy.org/2015/11/06/lost-in-transmission-how-much-electricity-disappears-between-a-power-plant-and-your-plug/. Accessed 15 May 2023.
2. Georgia State University. "Critical Magnetic Field and Critical Current." Hyperphysics, http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/scbc2.html. Accessed 15 May 2023.

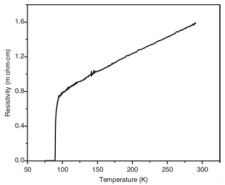
Objective

What are the essential differences between ordinary metals and superconductors?

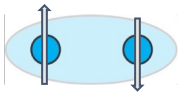
Should we consider this quantum phase for next-generation power transmission?



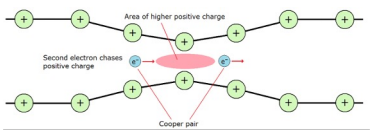
Essentials of Superconductivity



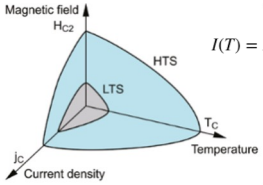
Superconductors exhibit a loss in resistance below their critical temperature (T_c)



Above T_c : electrons = fermions (half-integer spin)
-> cannot occupy same state (Pauli exclusion principle)
Below T_c : electron pair ~ bosons (integer spin)
-> can occupy same ground state, the superconducting state!



Why do the electrons pair?
As electrons flow through the lattice of positive ions in a superconductor, they can induce deformation, drawing in another electron, and forming a "Cooper pair"



$$I(T) = I_c(0)[1 - (T/T_c)^2]$$

High temperatures can cause the electrons to "unpair" at T_c

Magnetic fields can also induce a similar despairing process via a centrifugal force, causing despairing at H_c

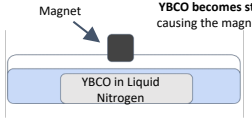
As current flows, it generates a magnetic field and thus with sufficient current can also destroy the superconducting state at I_c

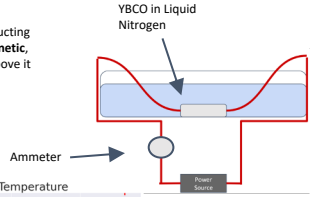
Experimental Demonstration

Two Aspects of Superconductivity

Perfect Diamagnetism

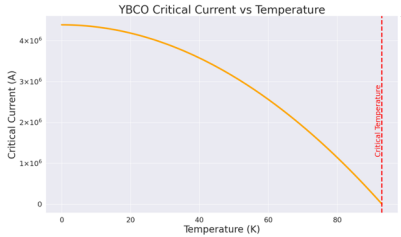
At low temperatures, superconducting **YBCO becomes strongly diamagnetic**, causing the magnet to levitate above it





Zero Resistance

While maintaining a constant voltage, **YBCO should not limit the amount of current** that can pass through due to its superconductivity.



A Tsunami of Electricity

As the temperature is lowered below the transition, the critical current the wire can support begins to grow, eventually allowing megaamps of current to flood through the wire

Dreams of a SuperGrid

How much power could superconducting transmission lines provide in comparison to existing copper lines?

High temperature superconductor (YBCO) at 77K: **6700x more homes**
High pressure, high temperature superconductor (LaH10) at 77K: **18400x more homes**
*relative to an equivalent copper transmission line at room temperature

Liquid Nitrogen Cooled Power Line
SuperLink, Munich