High Temperature Superconductivity: from basic science to implementation

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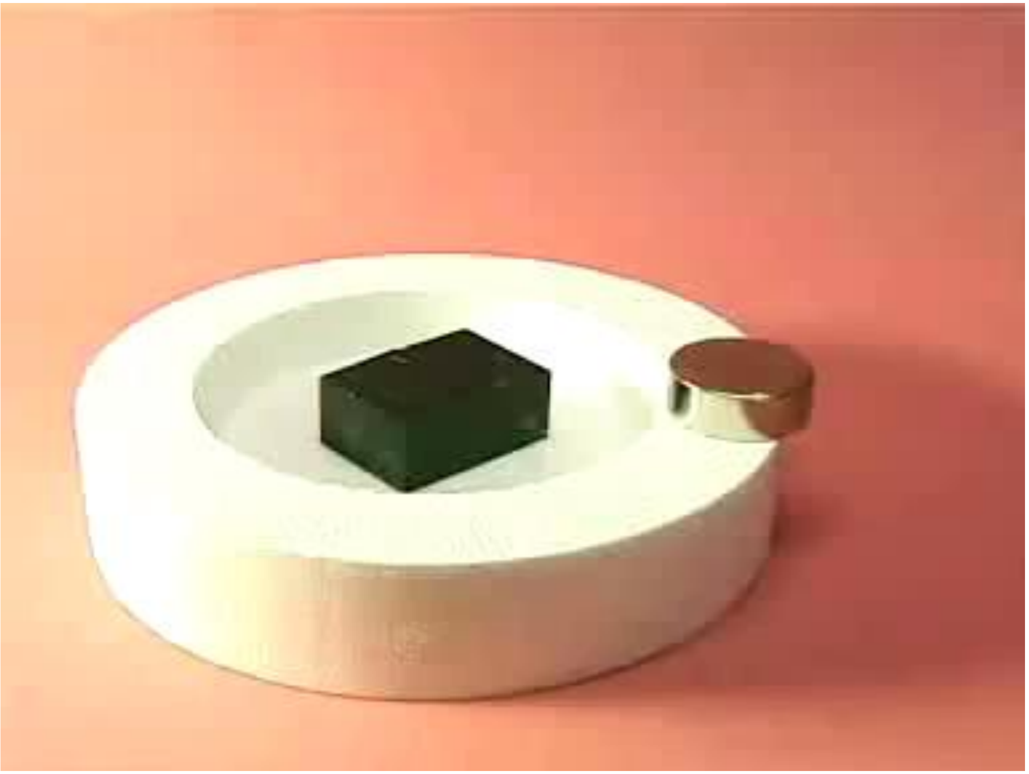
What is Superconductivity?



What is Superconductivity?

Below a certain critical temperature (T_c) the electrical resistance of certain materials goes to zero.

Meissner effect leads to expulsion of magnetic flux from interior.

A microscopic perspective

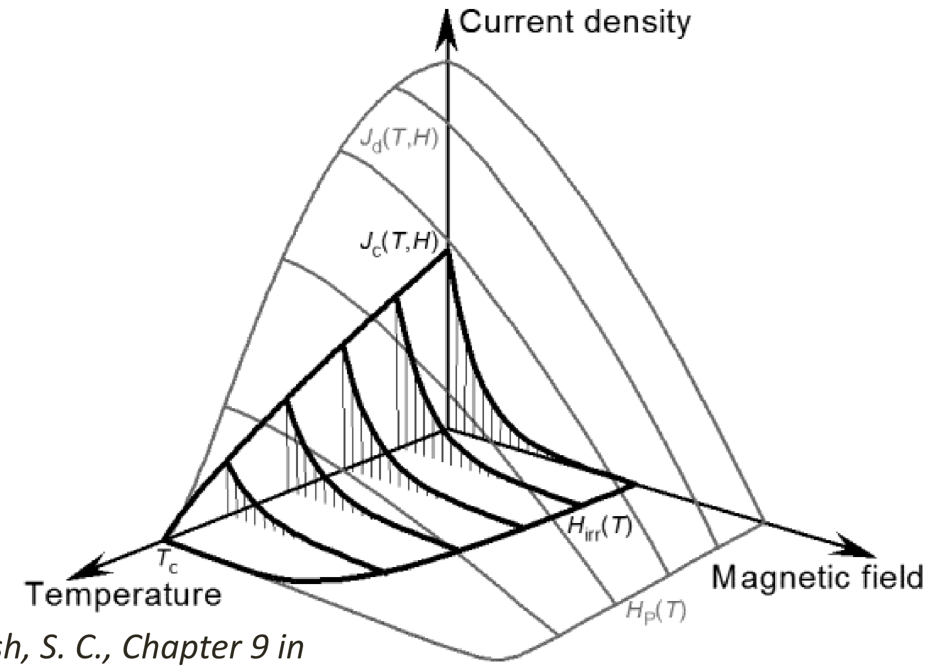
- Cold electron gas leads to filled “Fermi sea” of electrons.
- Presence of weak pairing interaction leads to the formation of a ground state of “Cooper pairs”.
- Cooper pairs act as bosons, so can macroscopically occupy the BCS ground state.
- Cooper pairs in this ground state are what is causing resistance free conduction.
- In HTS the question is where this pairing interaction comes from.

As it stands

- Phenomenon of Superconductivity discovered in 1911.
- Microscopic understanding from BCS theory.
- High Temperature Superconducting ceramics initially discovered in 1986.
- The basic physics of HTS remains unsolved…

Problems

- Even for HTS the typical critical temperature is T_c~100K
- High temperature superconductors generally ceramics, therefore not ductile.
- Limitations in current densities and external magnetic field strengths.



Taken from Wimbush, S. C., Chapter 9 in Materials for sustainable energy applications [1].

First Generation wires

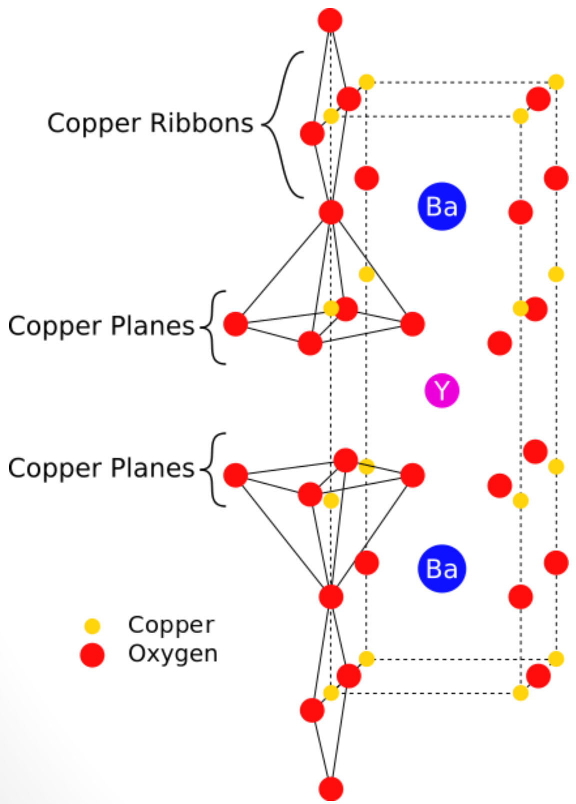
BSCCO $Bi_2Sr_2Ca_{n-1}O_{2n+4+\delta}$ discovered in 1988.

High critical current density at low temperature, and under high fields compared with LTS. Prior to MGB_2 this was the only one able to be made into round wire.

Bi2212 (T_c=85K, high field magnets), Bi2223 (T_c=110K, energy applications).

Second Generation

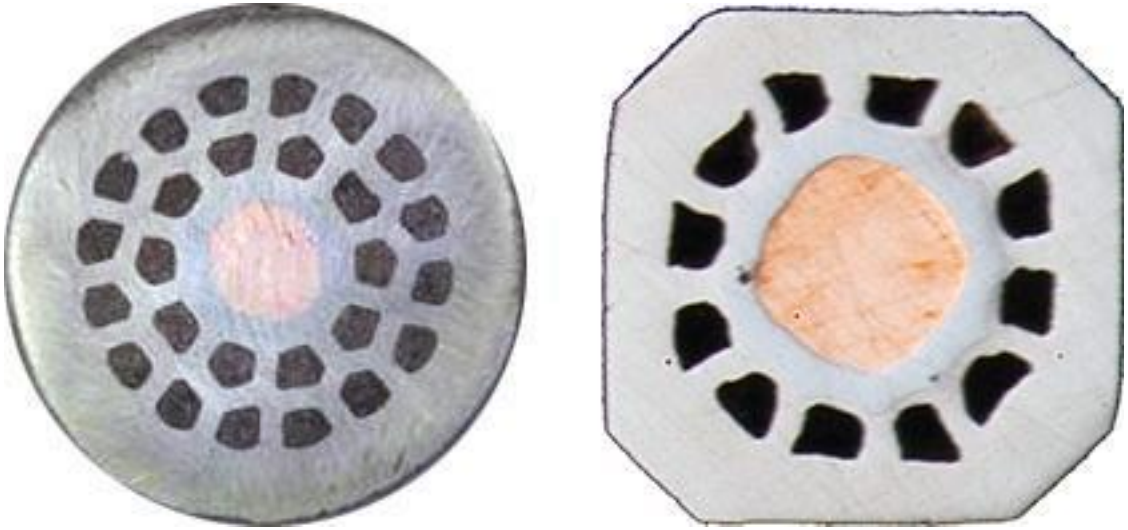
- RBCO $RBa_2Cu_3O_{7-\delta}$ (*R* is a rare earth element, e.g. Sc, Y or a lanthanoid).
- Used in epitaxially grown films.



Part of the lattice of Yttrium Barium Copper Oxide.
Source: Wikipedia.

MgB_2

- Low cost alternative.
- Lower T_c but can be practically useful.
- Can be used in a closed loop.



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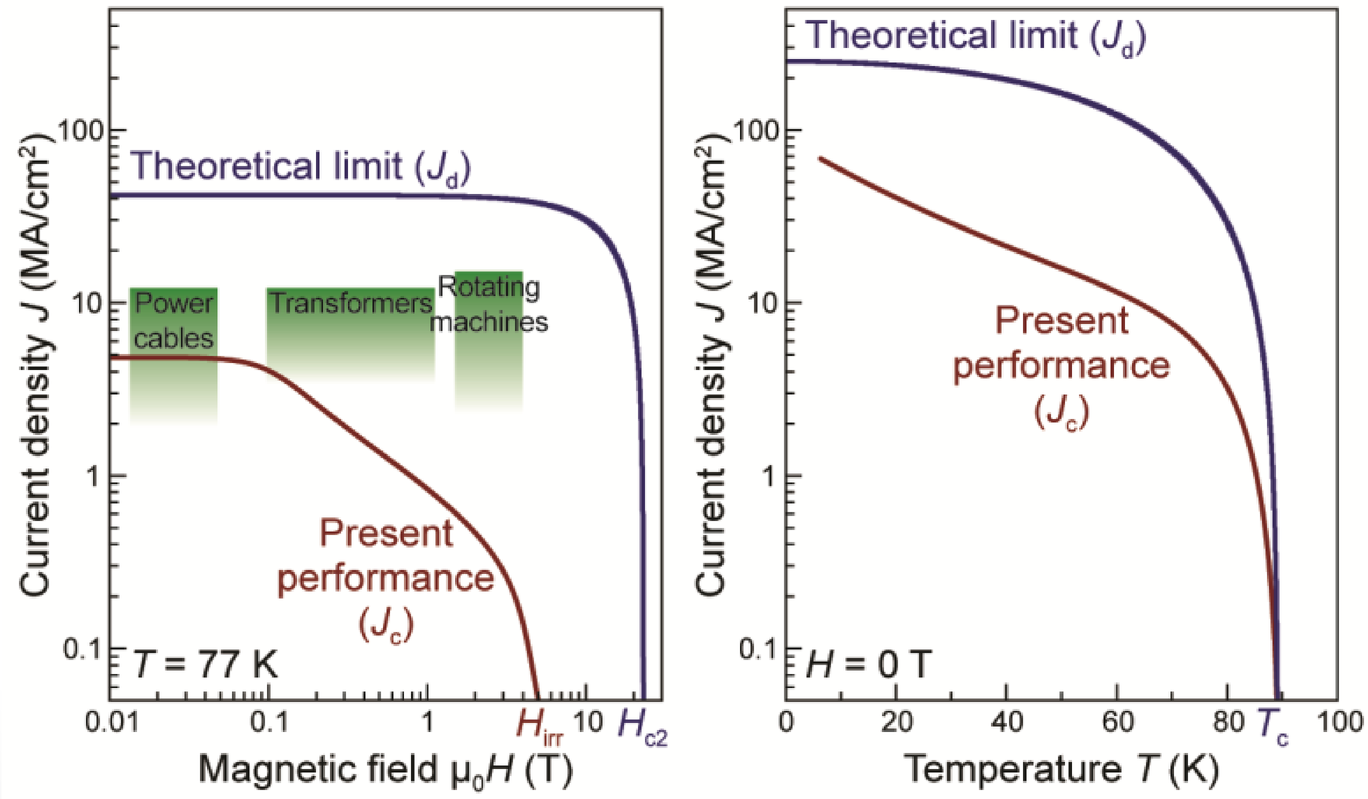
Critical Current Densities



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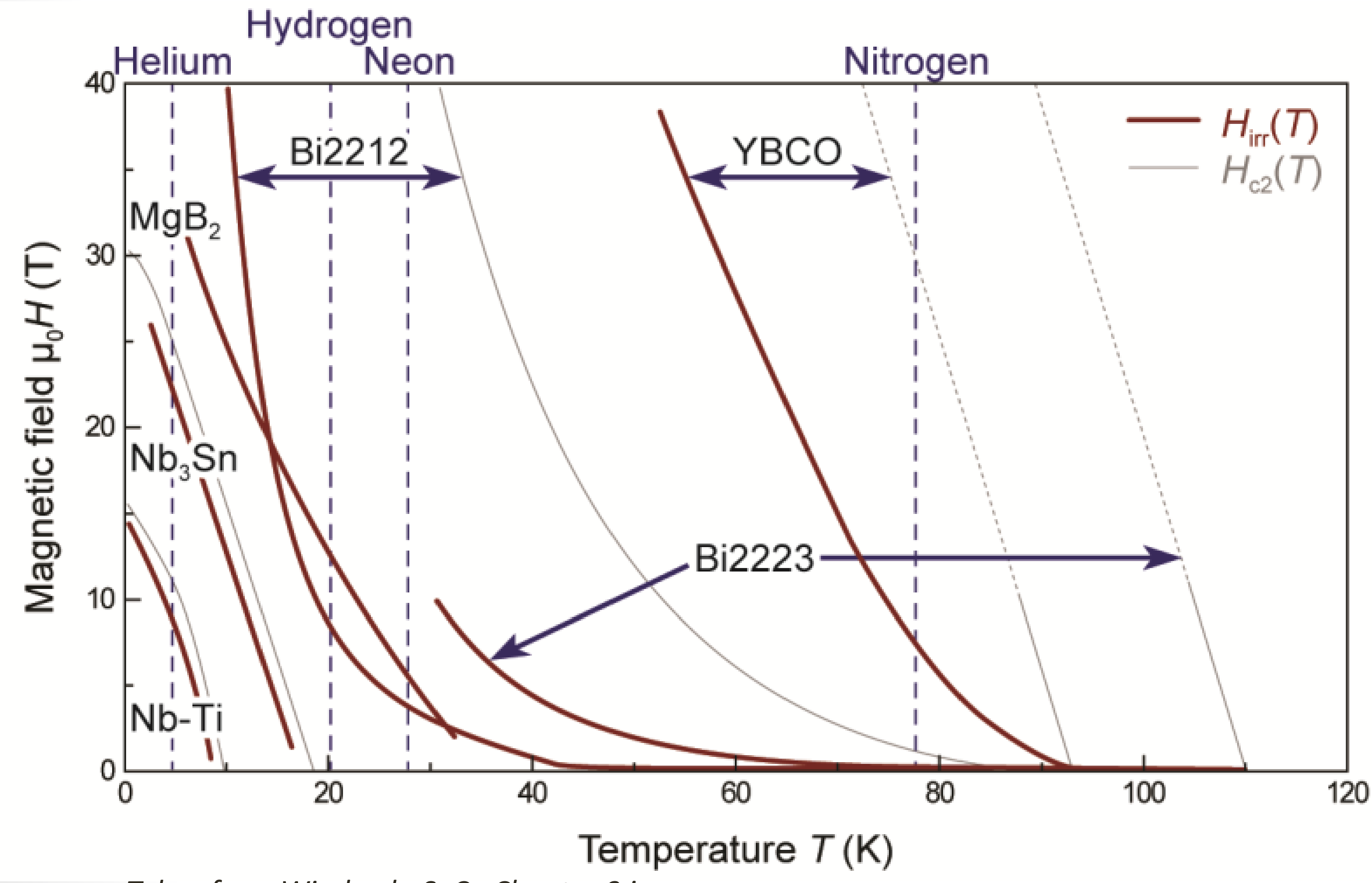
Comparison



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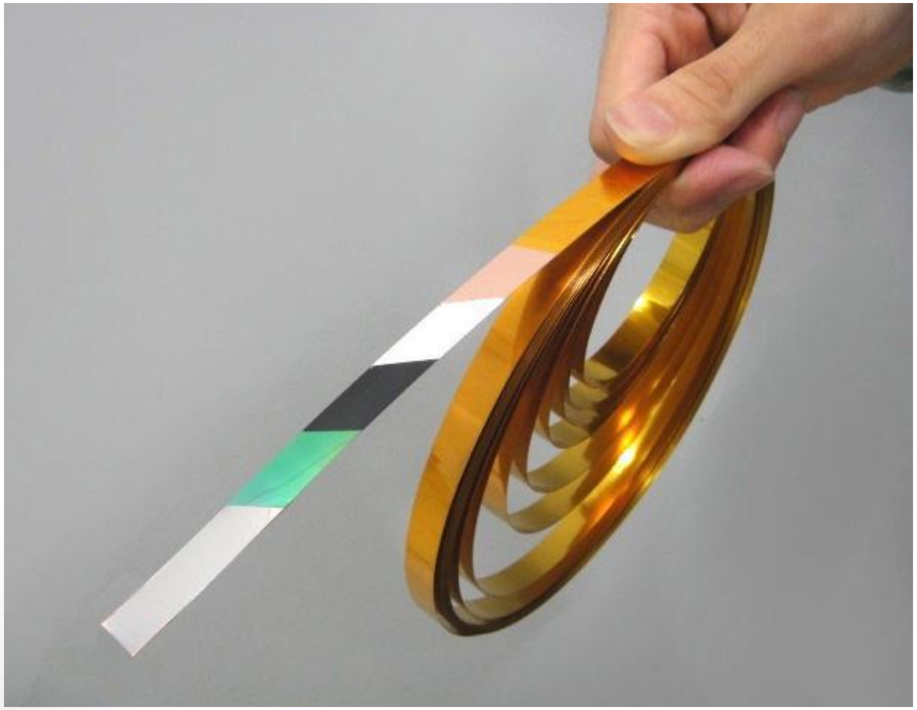
Applications

- Power cables. Could allow effective distributed power generation. Difficult due to scale and cooling requirements. 5-10% energy loss reduced to 0.5%. Halving of total loss still feasible even when cooling taken into account.



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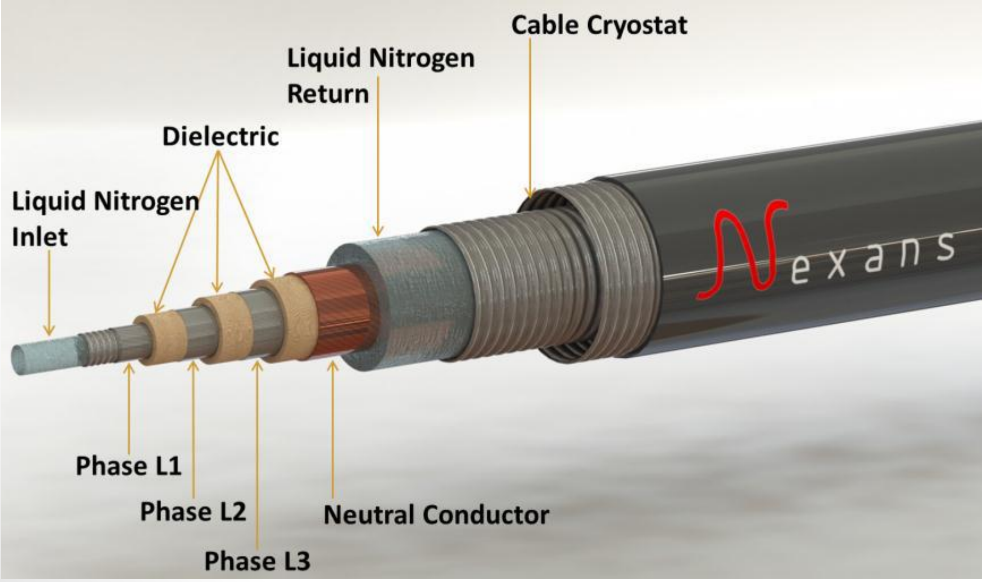
Power Cables: Implementation

First on grid installation in 2001 in Copenhagen.

First practical implementation into grid in the AmpaCity project in Essen, Germany (2014). 1km, 10kV to replace 110kV connection between two substations.

Finance: 5.9 million euros govt, 13.5 million private sector.



A three-phase concentric (triax) “cold dielectric” power cable assembled from superconductor tapes, featuring contraflow liquid cryogen pathways and an evacuated thermal insulation sleeve. *Image courtesy of Nexans.*

Energy Storage

- Superconducting Magnetic Energy Storage (SMES) devices with potential capability of 5GWh of electricity.
- Superconducting flywheels.

Grid Applications

- Potential to reduce number of transformer stations required for high voltage transmission.
- Superconducting transformers and generators could benefit from decreased mass.
- Current fault limiters. Issue is in damage to superconducting material during “fault” phase. Recently implemented by Nexans in Saxony, Germany.

Transportation

- Superconducting motors.
- Magnetically levitated trains. Yamanashi prefecture, Japan. Speeds > 500km/h.
- Uses LTS Nb-Ti magnet coils.

Cost

- Conventional Cu cable at RT: \$30-60/kA-m
- LTS superconducting cable: \$1/kA-m at 4.2K,2T.
- 1G HTS \$200/kA-m at 77K, 0T (\$20/kA-m at 20K).
- 2G HTS \$100/kA-m at 77K, 0T (predicted).
- MgB_2 \$1/kA-m at 25K, 1T (predicted).

Costs exclude cooling.

Room Temperature Superconductors?

Moral of the story: T_c isn't everything, given a workable cooling system.

References

[1] Wimbush, S. C. (unpublished). Chapter 9: Superconductors. In Moya, X. and Munoz-Rojaz, D. *Materials for sustainable energy applications*.

Thanks to Stuart C. Wimbush for providing me with a copy of his chapter on superconductor applications.