Crash Course in Materials Science of Superconductors

Stefan Bringuier

Materials Scientist
ORCID: 0000-0001-6753-1437
stefanbringuier@gmail.com
https://stefanbringuier.info

Sep 14, 2023

This document provides basic review of superconducting materials from a materials science & engineering perspective. This entails a very basic review of conductivity, magnetism, and superconductivity theory. The remainder is focused on aspects of specific material systems, such as compositional phases that exhibit superconducting phase, mechanical properties, and processing. High-level review of applications is also provided. The intent of this document is to act as a quick digest for someone who plans to dive deeper into the provided references.

Table of contents

List of Figures

Some Comments

! Important

These are working notes, so there are bound to be errors. Please keep this in mind while going through the notes. Feel free to email me if you want to provide corrections.

Note

Much of the notes derived from various sources, please checkout the references.

Tip

If you prefer to view this in a report format, you can download a formatted PDF of this presentation here.

Whats all the fuss

- Why did anyone care to begin with?
  - They didn't. Initially Heike Kamerlingh Onnes[1] and others were just interested in cryogenics.
  - Once they achieved liquid Helium, they asked why note study conductive metals at these temperatures.
  - In 1911 Kamerlingh Onnes started with elemental Mercury, the field of superconductivity (SC) was born.
- Physcist focused on measurement of other elemental solides and a theory.
- Observation of SC in Nb is really what begun technological use.

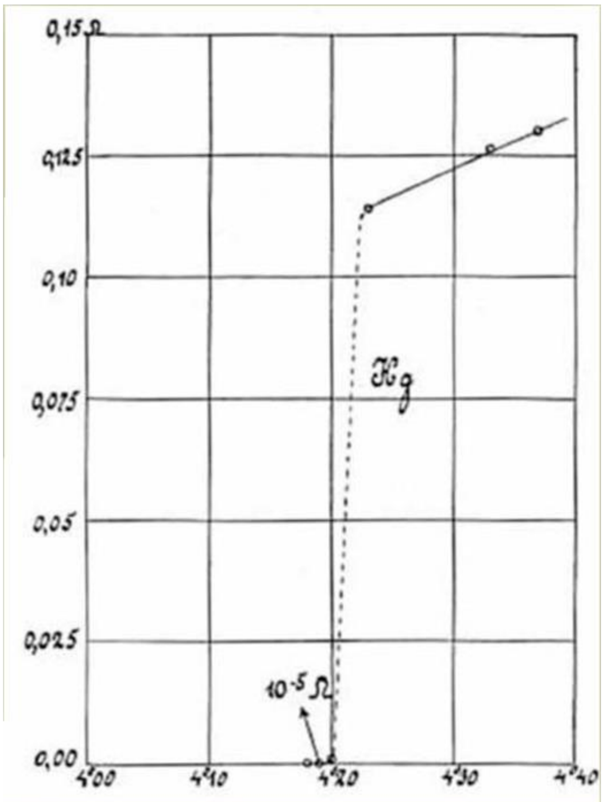

Figure 1: Original plot of Hg transition temperature to SC phase[1].

SC: Superconductivity. Nb: Niobium

Technological Interest

Magnetic Resonance Imaging

- Superconducting coils allow for high magnetic fields need to image nuclear resoance in human body.

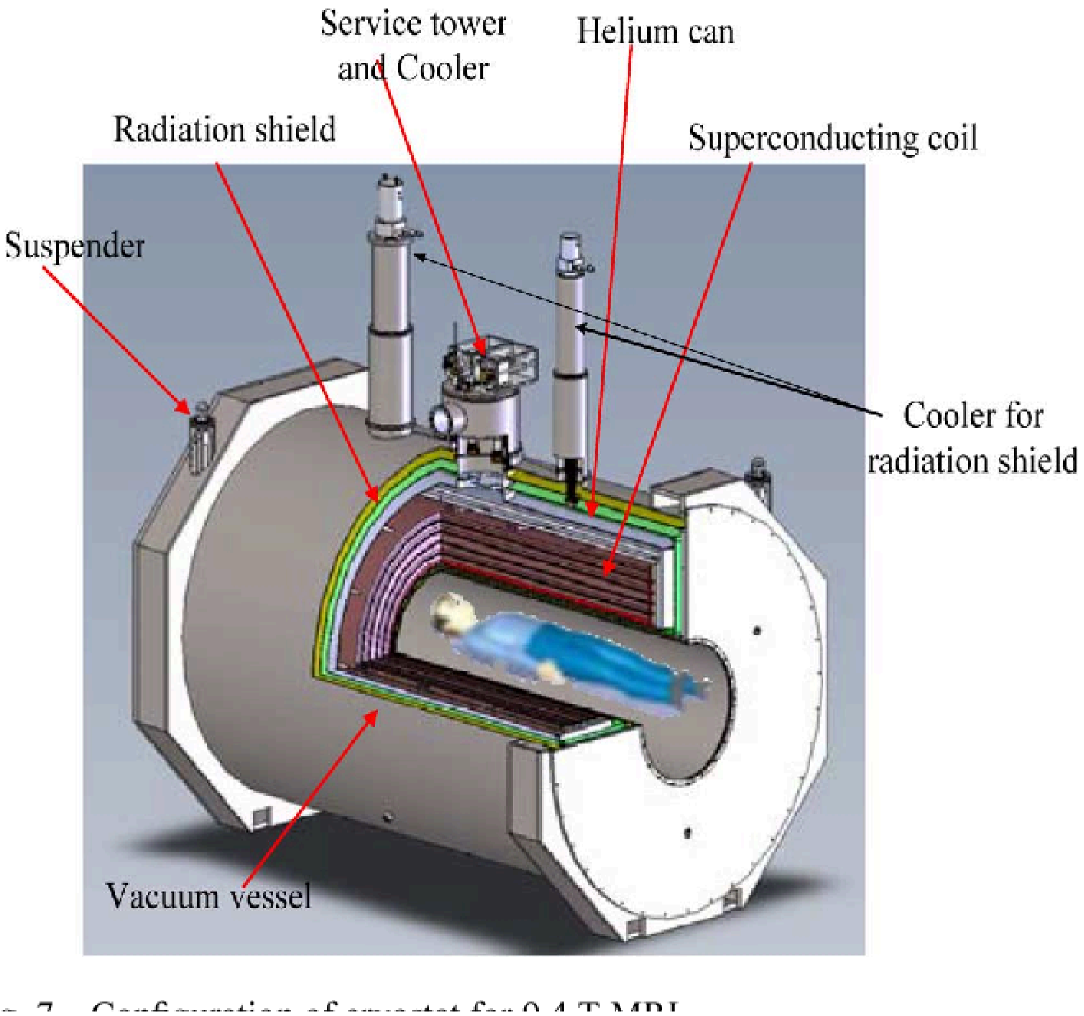

Figure 2: Cut-throught showing MRI machine and SC coils[2].

MagLev Trains

- Superconducting materials enable high-speed rail.

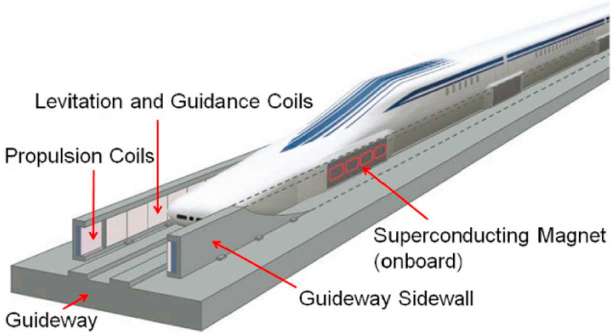

Figure 3: Superconductors are onboard train which interact with propolsion rail coils[3].

Energy Storage/Production

Backmatter

stefanbringuier@gmail.com

> **Note**
>
> This presentation can be viewed online at https://stefanbringuier.github.io/CrashCourseSCMaterials.
> To export `revealjs` presentations to pdf, press 'e' then 'ctrl-p' 'save as pdf'

> **Tip**
>
> A report formated PDF of this presentation can be downloaded here.

References

1. Delft, D. van & Kes, P. The discovery of superconductivity. *Physics Today* **63,** 38–43 (2010).

2. Wang, Q. L., Dai, Y. M., Zhao, B., Song, S. S., Wang, C. Q., Li, L., Cheng, J., Chen, S., Wang, H., Ni, Z., Li, Y., Cui, C., Hu, X., Lei, Y., Chan, K., Yan, L., Wen, C., Hui, G., Yang, W. C., Liu, F., Zhuo, Y., Zhou, X., Yan, Z., Chen, J. & Xu, T. A superconducting magnet system for whole-body metabolism imaging. *IEEE Transactions on Applied Superconductivity* **22,** 4400905–4400905 (2012).
3. Nishijima, S., Eckroad, S., Marian, A., Choi, K., Kim, W. S., Terai, M., Deng, Z., Zheng, J., Wang, J., Umemoto, K., Du, J., Febvre, P., Keenan, S., Mukhanov, O., Cooley, L. D., Foley, C. P., Hassenzahl, W. V. & Izumi, M. Superconductivity and the environment: A roadmap. *Superconductor Science and Technology* **26,** 113001 (2013).
4. Speller, S. *A materials science guide to superconductors and how to make them super.* (Oxford University Press, 2022).

Draft Outline

- Slide 4: Importance of Superconducting Materials
- Slide 5: Brief History of Superconductivity
- Applications: Magnetics and Wires
  - MRI Machines
  - Maglev Trains
  - Energy Grids
  - Superconducting Coils
  - Limitations in Applications
- Basics of Superconductivity (Theory)
  - Cooper Pairs
  - Meissner Effect
  - BCS Theory Overview
  - Zero Electrical Resistance
  - Critical Temperature
- Thermodynamics and Phases
  - Type I and Type II Superconductors
  - Critical Fields
  - Diamagnetic Response
  - Phase Diagrams
  - Energy Gaps
- Flux Pinning and Levitation
  - Vortex Lattices
  - Flux Tubes

- Levitation Applications
  - Pinning Centers
  - YBaCuO Examples

- Niobium-Titanium (NbTi) Alloys
  - Composition and Structure
  - Magnetic Properties
  - Mechanical Properties
  - Applications
  - Processing Challenges

- Quantum Effects
  - Quantum Tunneling
  - Josephson Junctions
  - Macroscopic Quantum Phenomena
  - SQUIDs
  - Quantum Computing Applications

- Microstructure and Grain Boundaries
  - Grain Boundary Impact on Properties
  - Microstructure Analysis
  - Sintering Methods
  - Weak Links
  - Influence on Flux Pinning

- Mechanical Properties
  - Tensile Strength
  - Brittleness
  - Fatigue
  - Thermal Expansion
  - Composite Superconductors

- High-Temperature Superconductors (HTSC)
  - YBaCuO and Other Cuprates
  - Iron-based Superconductors
  - Challenges and Advantages
  - Applications
  - Current Research Trends

- Recent Trends and Future Directions
  - MgB2 Developments
  - Supposidly Room-Temperature Superconductors

  - Topological Superconductors
  - Commercialization Challenges
  - Research Funding and Outlook

- Conclusion and Summary

  - Summary of Key Points