Superconductivity

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Outline

- Superconductivity and its classifications
- The Meissner Effect
- The London Equations and BCS Theory
- Type II conductors
- Applications
Superconductivity

- A superconductor is a material that, when cooled below a critical temperature, exhibits zero electrical resistance.
- Discovered by Heike Onnes in 1911 while studying cryogenic solid mercury.
- Best explained as a quantum mechanical phenomenon.
Classifications of Superconductors

- **Type I** – “soft” – low temperature (below 30K), made of pure metals, explained by BCS Theory, exhibits Meissner effect.

- **Type II** – “hard” – high temperature (or two temperatures), can be alloys or ceramics, not explained by BCS, does not completely exhibit Meissner effect.
The Meissner Effect

- The Meissner effect is an expulsion of a magnetic field from the interior of a superconductor.
- Discovered 1933, Meissner and Ochsenfeld.
- Different from diamagnet since an already present field will be expelled.
London Equations

\[ \frac{\partial j_s}{\partial t} = \frac{n_s e^2}{m} E, \quad \nabla \times j_s = -\frac{n_s e^2}{mc} B. \]

- Fritz and Heinz London related current to electromagnetic fields
- \( j_s \) is superconducting current density, \( n_s \) is the phenomenological constant

\[ B_\parallel(x) = B_0 e^{-x/\lambda}. \]
BCS Theory

- Pairs of electrons form Cooper pairs, and behave more like bosons than fermions
  - Cooper pairs – lattice interactions (phonons)

- Superconductivity caused by condensation of Cooper pairs
- Electron pairs have slightly lower energy, leaving a gap that inhibits collision interactions
Type II Theories

- Very complex, multi layered crystal structures that makes modeling difficult
- Resonating Valence Bond Theory – in copper oxide lattice, electrons from copper atoms interact to form a valence bond
  - Moving electrons create spin density functions, attract other electrons
- Spin Fluctuation – Cooper pairs formed by exchanging spin fluctuations
Applications

- Magnetic Levitation trains – no friction between train and track
- MRI/NMR – B fields add energy to hydrogen which give off this energy at different frequencies (LT)
- SQUID (Superconducting QUantum Interference Device) – detect extremely low B fields
- Particle accelerators – beam steering and accelerating particles
Conclusion

- Superconductors exhibit zero electrical resistance and (in many cases) exclude magnetic fields.
- The London equations model superconducting well, including the Meissner effect.
- BCS Theory accurately explains Type I conductors.
- Type II are still not understood very well.
- Many applications, however, cost, efficiency, and magnetic field effects need to be taken into account.

