Superconductivity

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Outline

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

Superconductivity

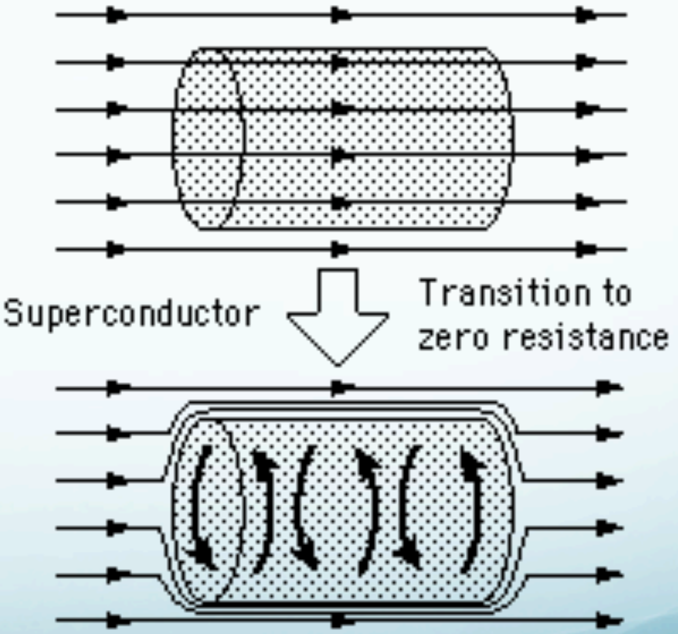
- A superconductor is a material that, when cooled below a critical temperature, exhibits zero electrical resistance
- Discovered by Heike Onnes in 1911 while studying cryogenic solid mercury
- Best explained as a quantum mechanical phenomenon

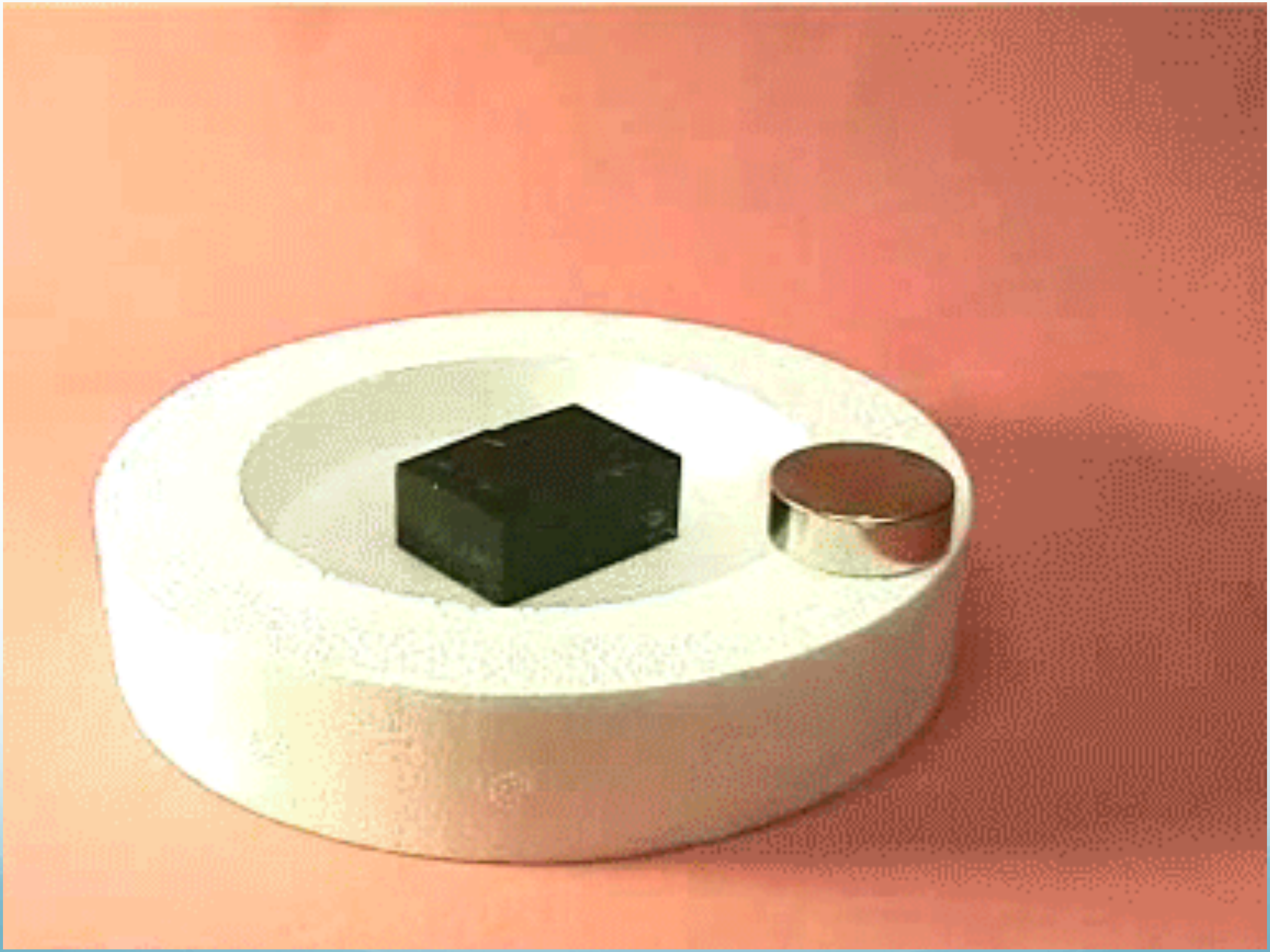
Classifications of Superconductors

- 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

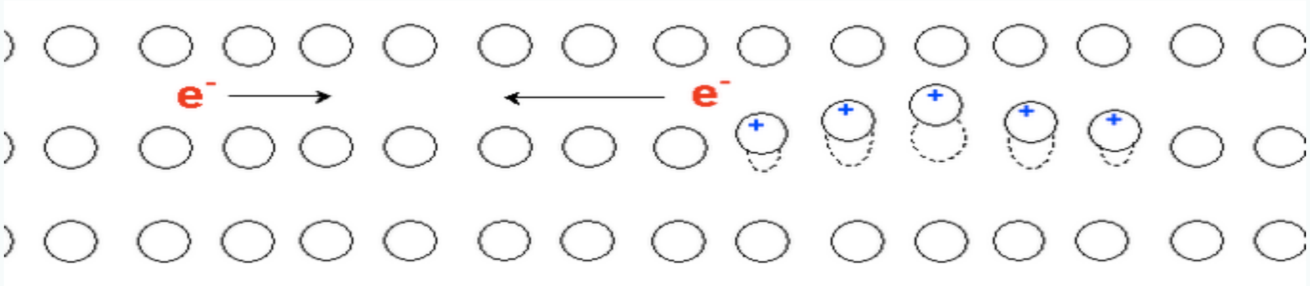
$$\frac{\partial \mathbf{j}_s}{\partial t} = \frac{n_s e^2}{m}\mathbf{E}, \qquad \nabla \times \mathbf{j}_s = -\frac{n_s e^2}{mc}\mathbf{B}.$$

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

$$B_z(x) = B_0 e^{-x/\lambda}.$$

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 exhibits 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

References

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