Muons in superconductors

- What are superconductors
- Measuring magnetic fields
- Extracting key length scales
- Understanding new physics

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Superconductors

Zero resistance state

Expels magnetic fields

More than just a perfect conductor
Magnetic Penetration

\[ B = \frac{1}{e} B_a \]

\[ \lambda_L \propto \frac{1}{n_s} \]

\[ B = B_a e^{-x/\lambda_L} \]

Can probe this directly using low energy muon implantation at different depths
Two Types of Superconductor

Type I

Type II

-4πM

H

H

H

H

H

H

H

H

H

H

H

H

H

H

H
Vortex lattice measurement

Muons measure a distribution of fields that depends on the penetration depth $\lambda$ and the coherence length $\xi$. 
How the measurement works

- Compare the field distribution above and below superconducting transition
- Difference is from the vortex lattice field distribution
What data do you get?

Temperature dependence

Field dependence

\[(\text{Ba,K})\text{Fe}_2\text{As}_2\] gives quantitative agreement with electronic band structure.
Applications – I

Determining properties of superconductors

- **Penetration depth** $\lambda$
  - Related to critical current
  - Maximum field without vortex penetration ($H_{c1}$)

- **Coherence length** $\xi$
  - Related to maximum superconducting field ($H_{c2}$)

- **Structure/symmetry of the superconducting energy gap**
  - Gives clues about the interactions driving superconductivity
Applications – II

• Finding trends in families of superconductors
  - Uemura plot
  - Phase diagrams for materials

• Understanding the physics of the vortex lattice
  - Vortex liquid and glass states
  - Pancake vortices

• Time-reversal symmetry breaking
  - Measure in zero applied field compensating any external fields
  - Tiny magnetic signal emerges
  - Very hard to measure otherwise
Practicalities

- Measure a sample in 1-2 days
- Field range: 0-60mT (ISIS), <9.5T (PSI)
- Temperature range: Above 0.02K
- Powders or crystals, 20mg < m < 3g