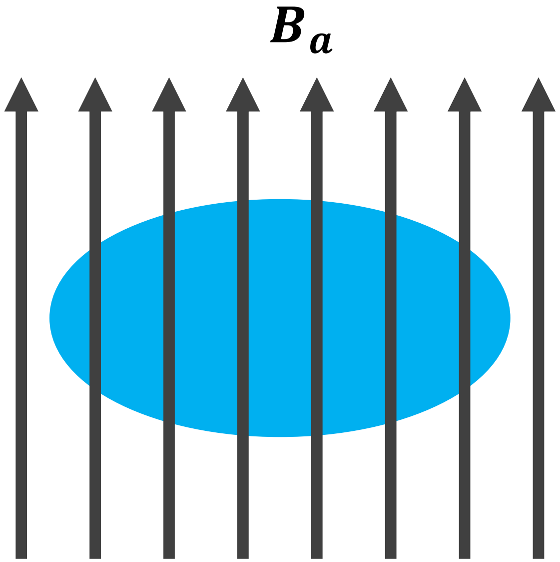
Chapter 2 Meissner Effect
Perfect Diamagnetism

Introduction

Experimental Methods

Summary

Perfect Conductor



$$\Phi = AB_a$$

Lenz's Law

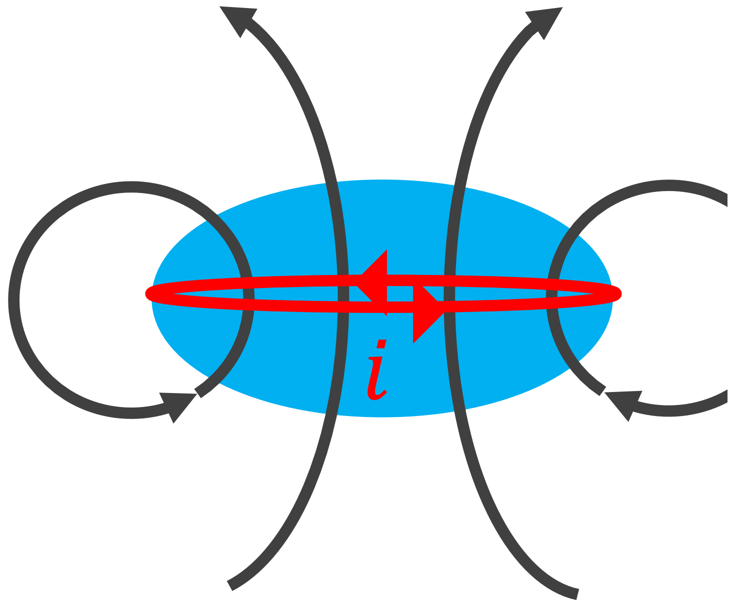
$$-A\frac{dB_a}{dt} = Ri + L\frac{di}{dt} \qquad (2.1)$$

R: resistance $\qquad$ L: inductance

$R = 0$ for a perfect conductor

$$-A\frac{dB_a}{dt} = L\frac{di}{dt} \qquad (2.2)$$

$$\Rightarrow Li + AB_a = constant \qquad (2.3)$$

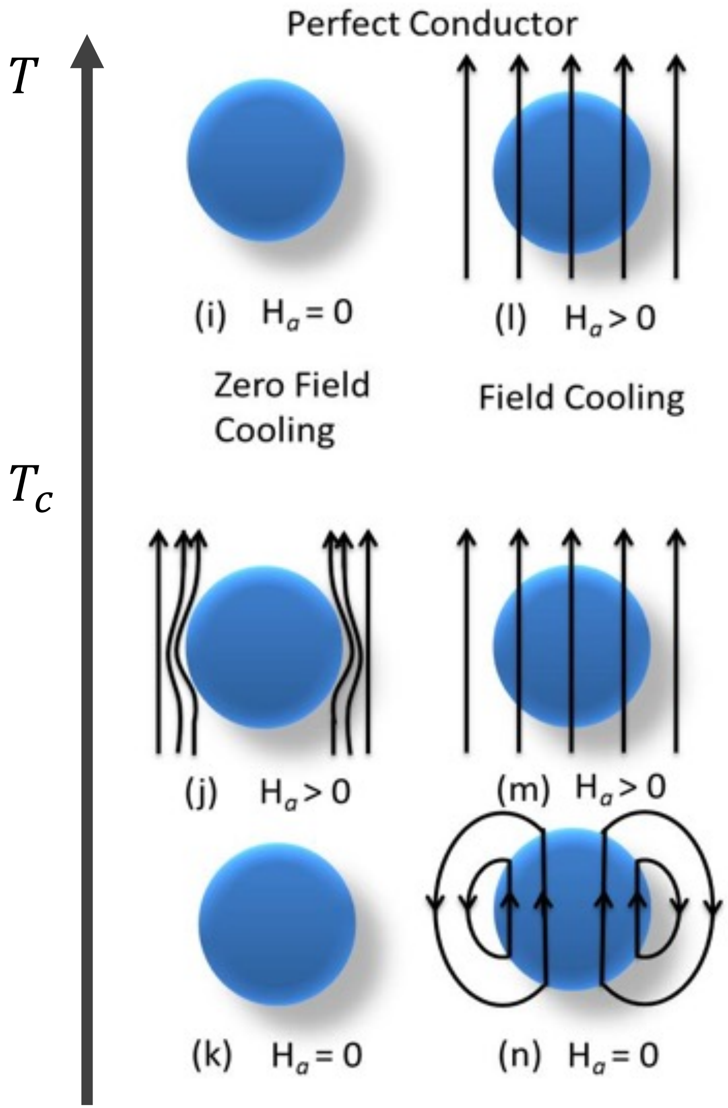


Total flux of a perfect conductor remains constant

Perfect Conductor

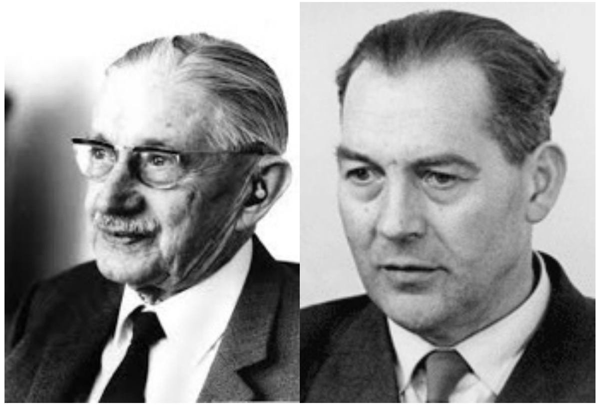
The magnetization of a perfect conductor depends on thermal and magnetic history!

Is this true for superconductor???

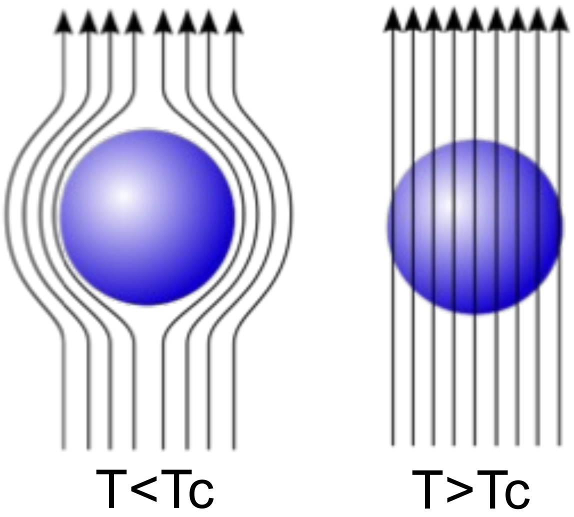


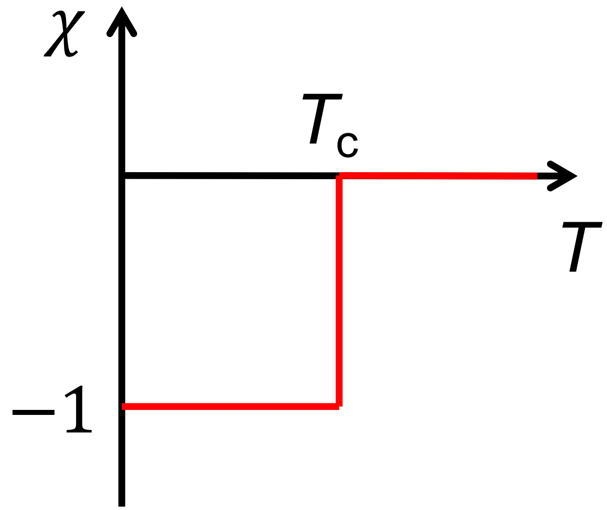
Total flux of a perfect conductor remains constant

Meissner Effect



W. Meissner, R. Ochsenfeld 1933



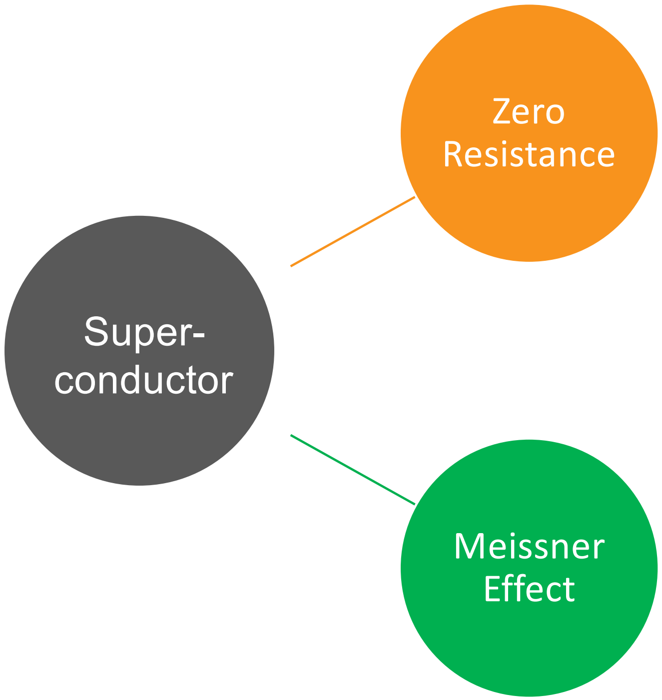


$$B = \mu_0(M + H) = \mu_0(1 + \chi)H$$

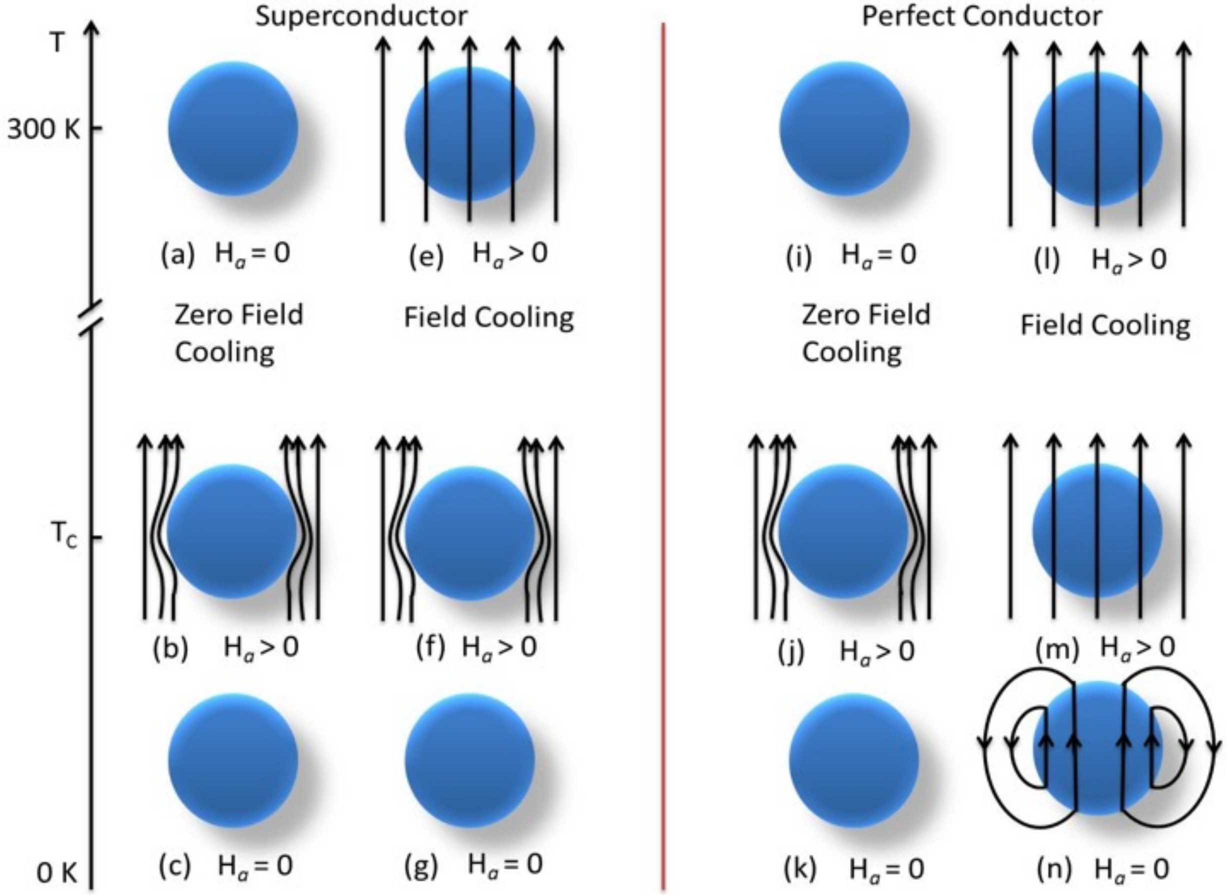
$$B = 0 \Rightarrow \begin{cases} M = -H \\ \chi = -1 \end{cases}$$

Perfect diamagnetism for superconductor

Introduction

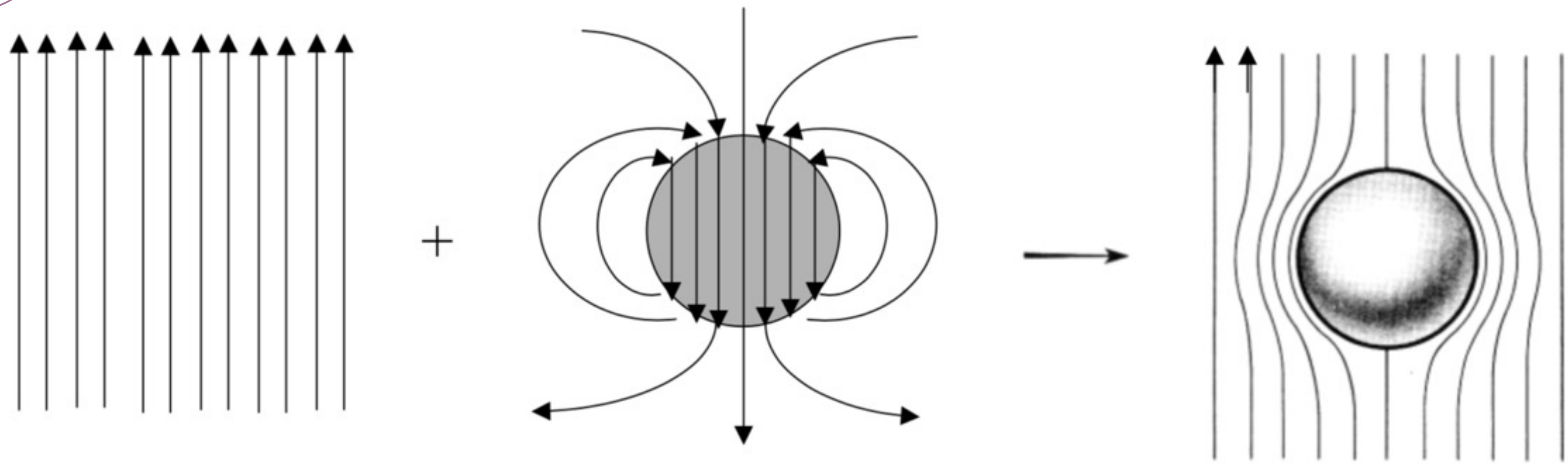


- Superconductor is not a perfect conductor!



Superconductor in the SC state never allow a magnetic flux density to exist in its interior.

Introduction



$B_{app} = \mu_0 H$

$M = -H$ (inside the sphere)

A dipole field outside the sphere

B

Meissner Effect

Introduction

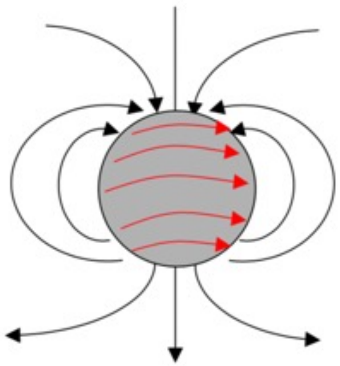
Surface currents

$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J}$

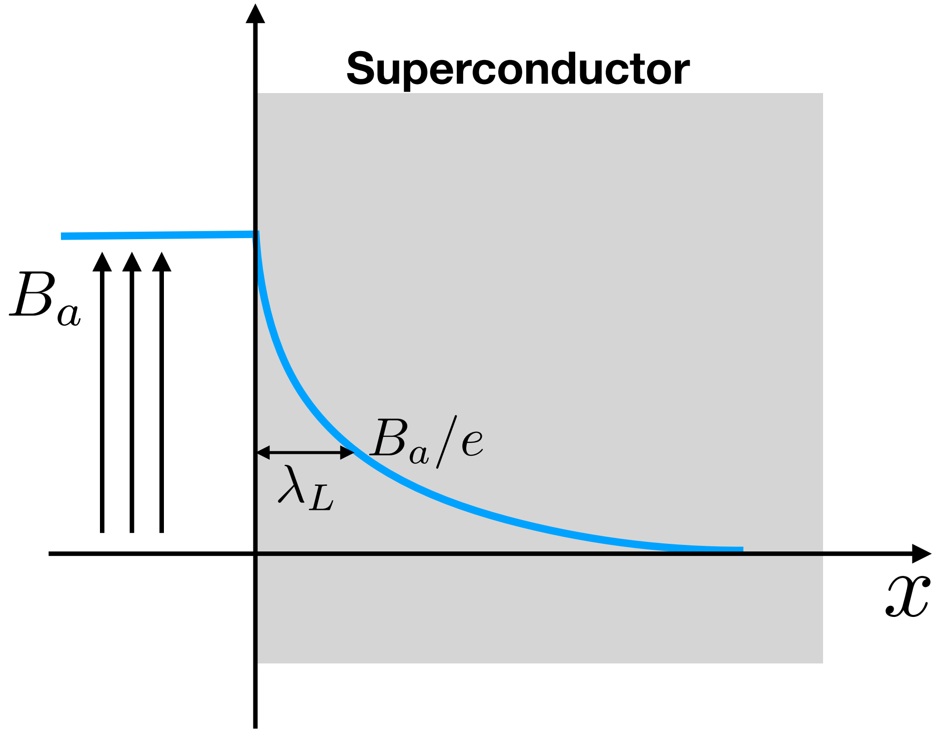
$\boldsymbol{B_{interior}} = \boldsymbol{0}$

$\boldsymbol{J_{interior}} = \boldsymbol{0}$

$\boldsymbol{J_{Suface}} = \boldsymbol{\nabla \times M}$



λ: Penetration depth
~10^{-8} m

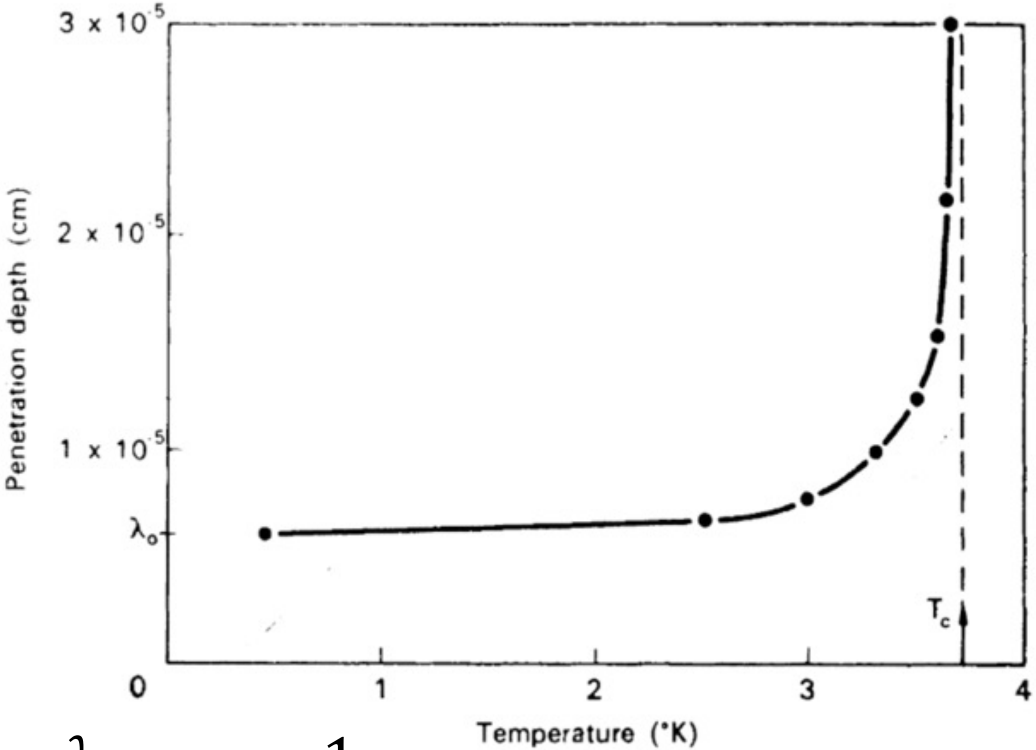


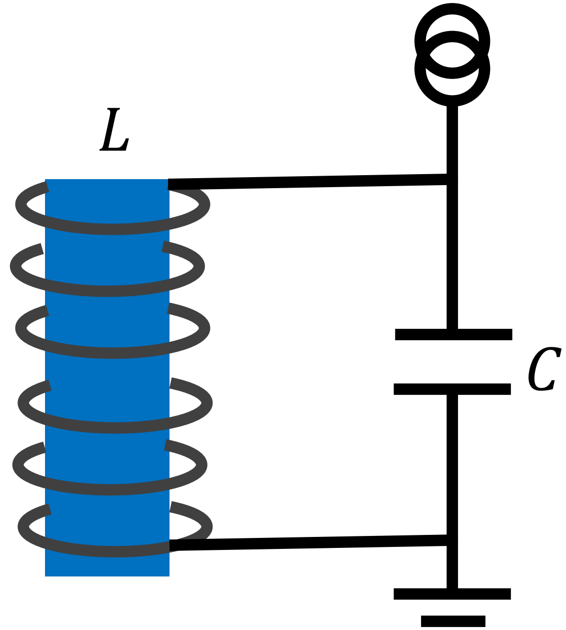
$B(x) = B(0)e^{-x/\lambda}$

London Theory

Penetration depth

Introduction





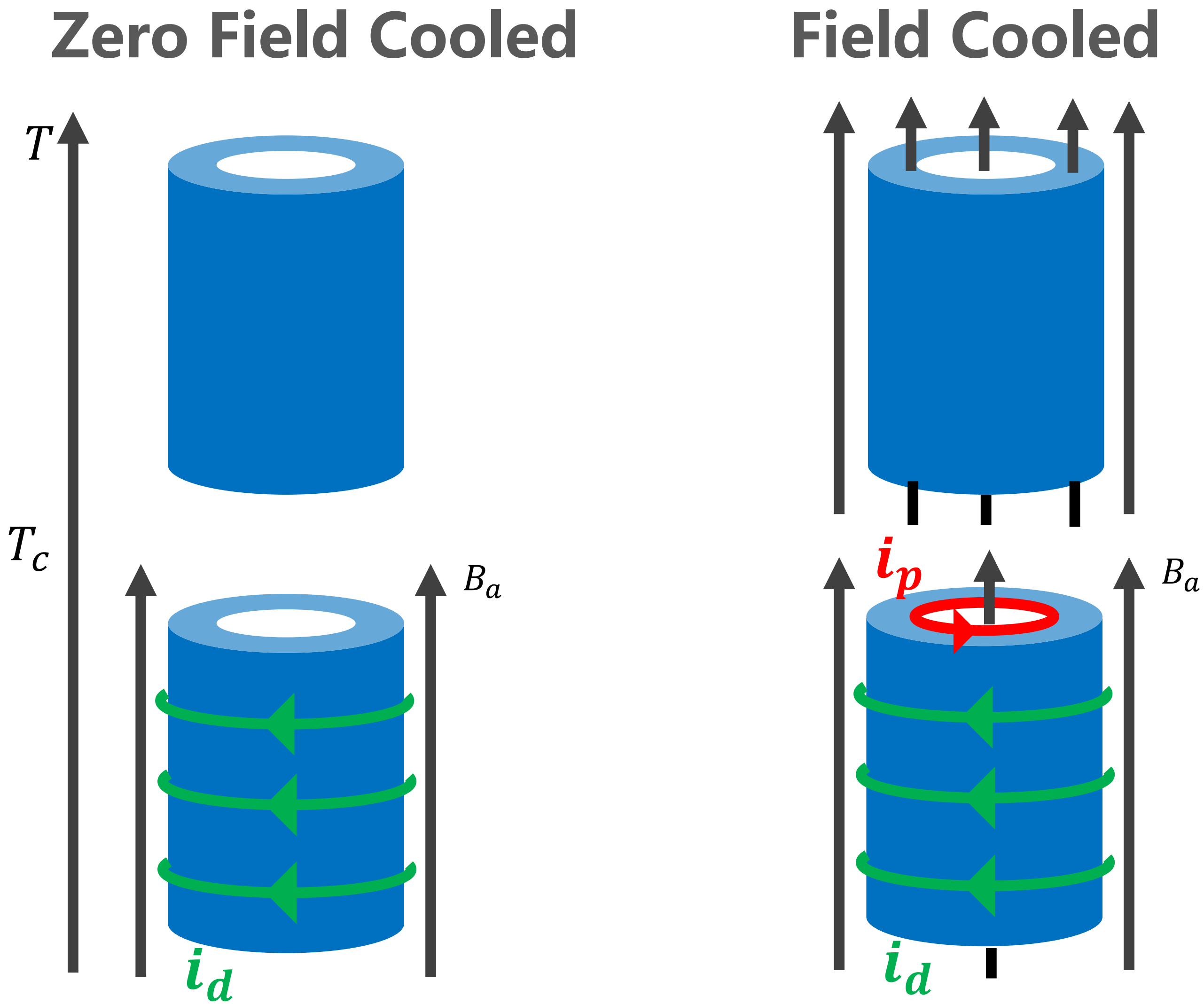
$$L = f(\lambda)$$

$$\frac{\lambda}{\lambda_0} \approx \frac{1}{(1 - t^4)^{1/2}} \qquad t = T/T_c$$

Oscillation frequency varies as λ changes with T

Penetration depth

Introduction



Hole in a superconductor

Chapter 2 Meissner Effect
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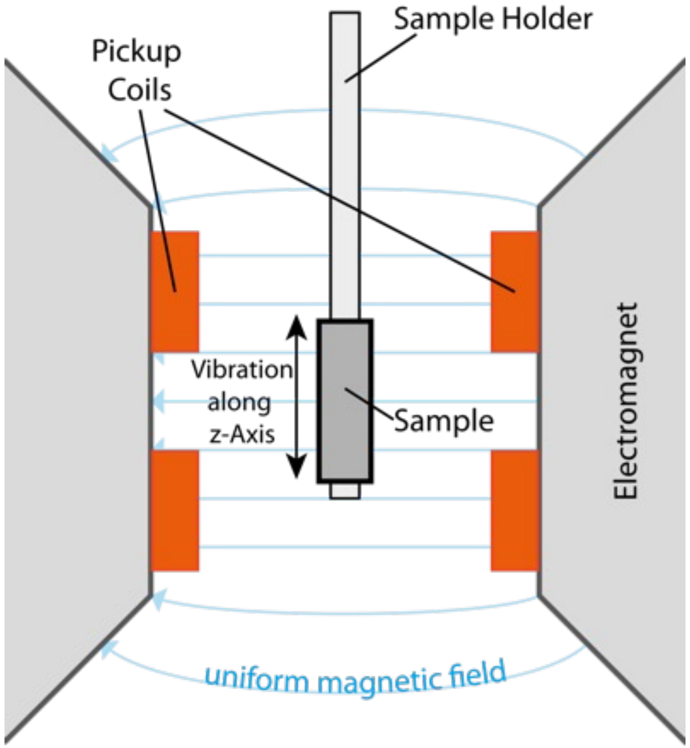
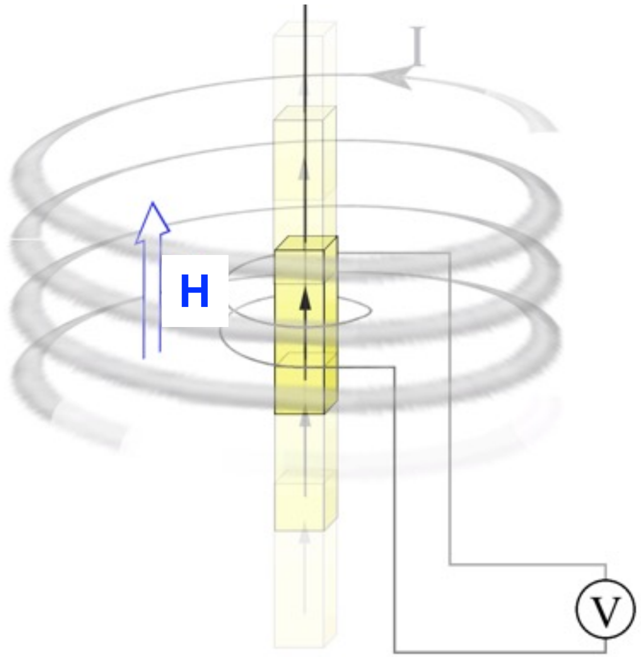
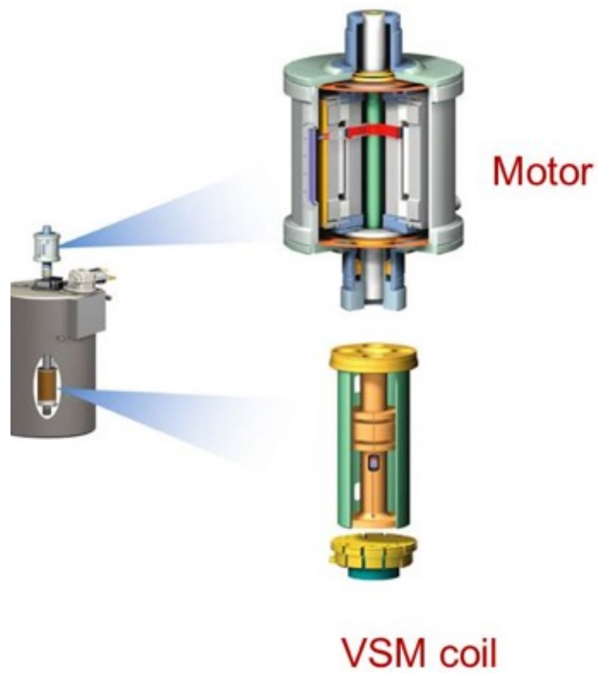
Experimental Methods



Simon Foner 1955



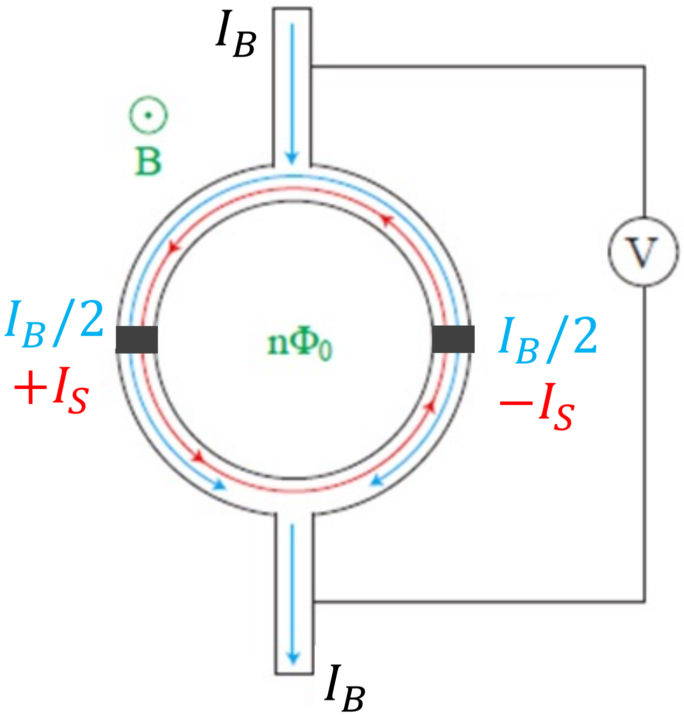
VSM contd.

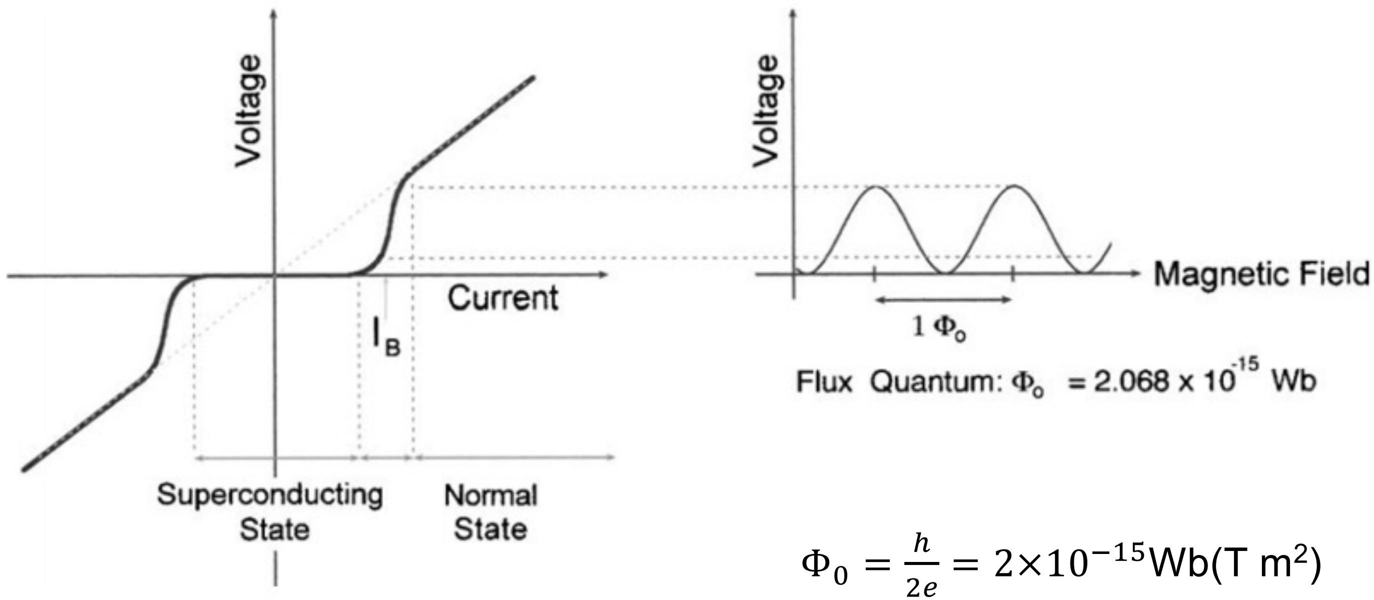


$$V \propto M$$

Vibrating-sample magnetometer (VSM)

Experimental Methods





$$\Phi_0 = \frac{h}{2e} = 2\times10^{-15}\text{Wb}(\text{T m}^2)$$

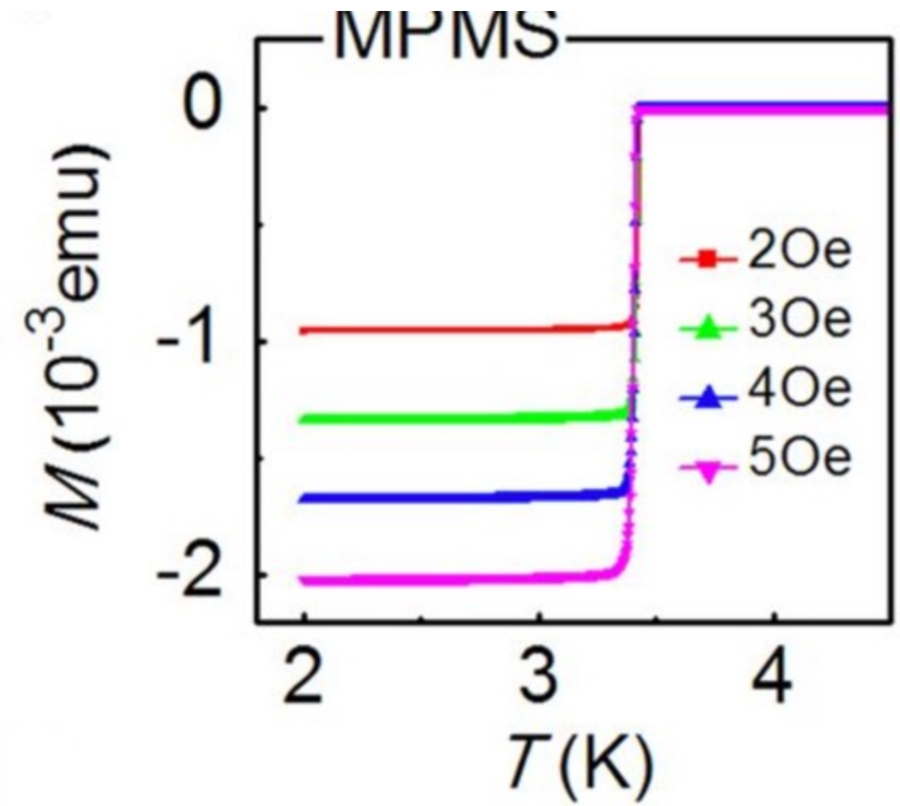
Sensitivity ~5×10^{-18} T

R. Jaklevic, J. J. Lambe, J. Mercereau, and A. Silver 1964

SQUID (superconducting quantum interference device)

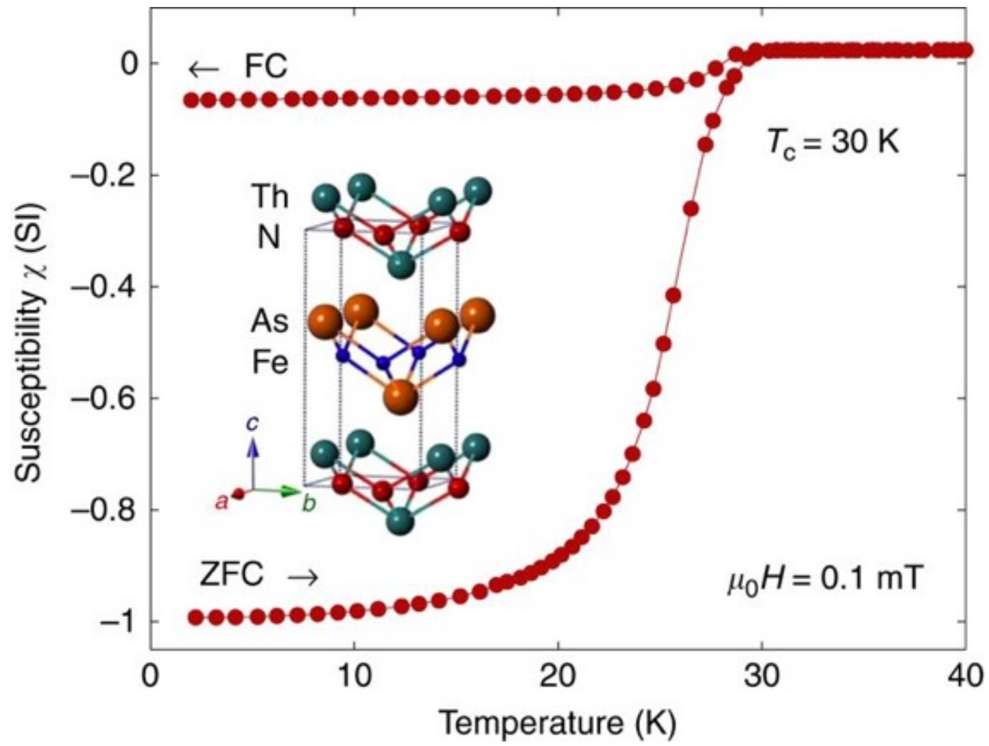
Magnetization

Experimental Methods



Type I

Long Wu et al., *Scientific Reports* **7** 45945 (2017)



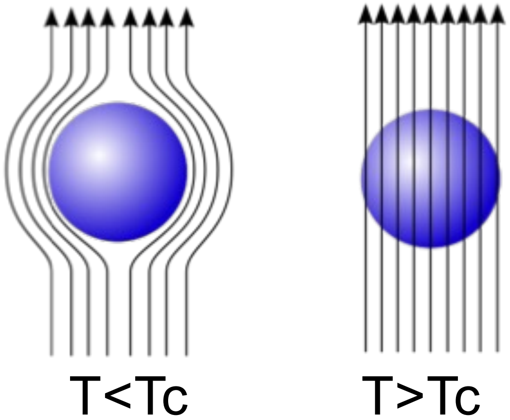
Type II

T. Shiroka et al., *Nature Communications* **8**, 156 (2017) |

Magnetization

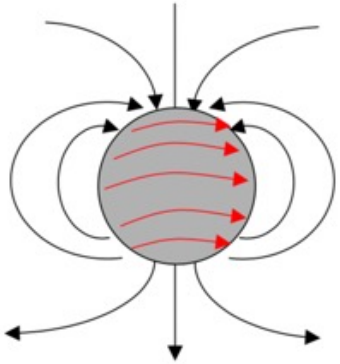
Summary

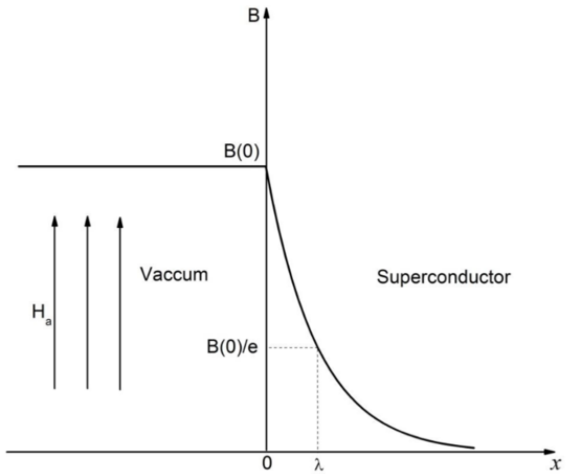
W. Meissner, R. Ochsenfeld 1933



Perfect diamagnetism

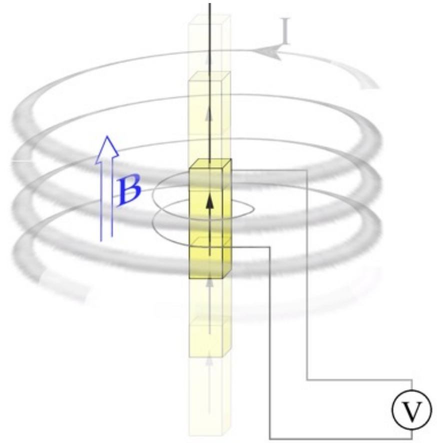
Surface currents

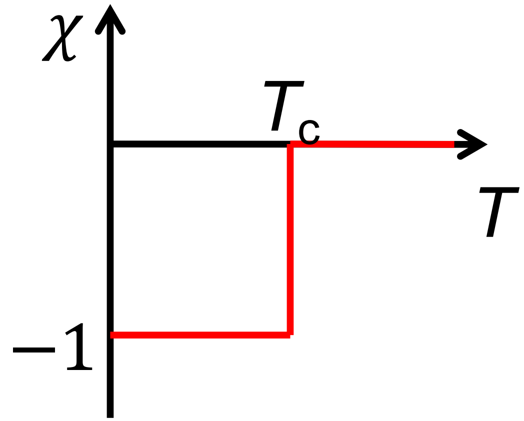




Penetration depth

VSM





Experimental evidences