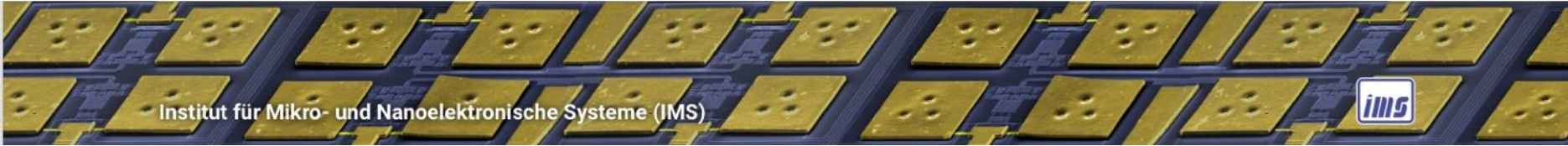
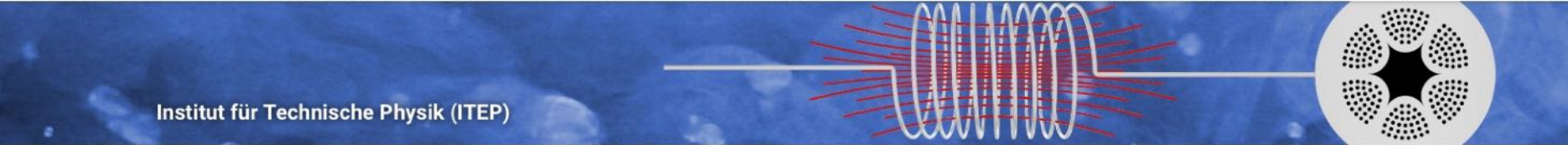


Superconductivity for Engineers

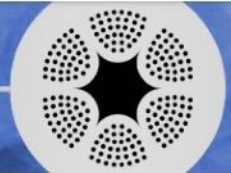
Prof. Dr. Sebastian Kempf, Prof. Dr. Bernhard Holzapfel
Summer term 2021



Institut für Mikro- und Nanoelektronische Systeme (IMS)



Institut für Technische Physik (ITEP)



(Preliminary) Schedule

	Day	Date	Lecture / Tutorial	Day	Date	Lecture / Tutorial
1	Mon	21-04-12	Lecture 1 (SK)	Wed	21-04-14	
2	Mon	21-04-19	Lecture 2 (BH)	Wed	21-04-21	
3	Mon	21-04-26	Lecture 3 (SK)	Wed	21-04-28	Tutorial 1 (IMS)
4	Mon	21-05-03	Lecture 4 (SK)	Wed	21-05-05	
5	Mon	21-05-10	Lecture 5 (SK)	Wed	21-05-12	~~Tutorial 2 (IMS)~~
6	Mon	21-05-17	Lecture 6 (SK)	Wed	21-05-19	Tutorial 2 (IMS)
7	Mon	21-05-24	---	Wed	21-05-26	
8	Mon	21-05-31	Lecture 7 (BH)	Wed	21-06-02	Tutorial 3 (IMS)
9	Mon	21-06-07	Lecture 8 (BH)	Wed	21-06-09	Tutorial 4 (ITEP)
10	Mon	21-06-14	Lecture 9 (BH)	Wed	21-06-16	
11	Mon	21-06-21	Lecture 10 (BH)	Wed	21-06-23	Tutorial 5 (ITEP)
12	Mon	21-06-28	Lecture 11 (BH)	Wed	21-06-30	
13	Mon	21-07-05	Lecture 12 (BH)	Wed	21-07-07	Tutorial 6 (ITEP)
14	Mon	21-07-12	Lecture 13 (SK)	Wed	21-07-14	
15	Mon	21-07-19	Lecture 14 (SK)	Wed	21-07-21	Tutorial 7 (IMS, ITEP)

(Preliminary) Lecture content

- Lecture 1: (SK) Introduction and overview
- Lecture 2: (BH) Superconductor applications
- Lecture 3: (SK) Normal metals and properties of the normal conducting state
- Lecture 4: (SK) **Perfect conductor, ideal diamagnetism, Two-Fluid-Model, London theory**
- Lecture 5: (SK) Disordered superconductors, Pippard theory, microwave properties
- Lecture 6: (SK) BCS theory
- Lecture 7: (BH) Ginzburg-Landau theory
- Lecture 8: (BH) Typ-I superconductors
- Lecture 9: (BH) Typ-II superconductors
- Lecture 10: (BH) Typ-II superconductors
- Lecture 11: (BH) Current transport, ac-losses, thermal aspects
- Lecture 12: (BH) Current transport, ac-losses, thermal aspects
- Lecture 13: (SK) Josephson junctions and SQUIDs
- Lecture 14: (SK) Josephson junctions and SQUIDs

Maxwell equations

Name	Integral equations	Differential equations
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E} \cdot d\mathbf{S} = \frac{1}{\varepsilon_0} \iiint_{\Omega} \rho dV$	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B} \cdot d\mathbf{S} = 0$	$\nabla \cdot \mathbf{B} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d}{dt} \iint_{\Sigma} \mathbf{B} \cdot d\mathbf{S}$	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 \left(\iint_{\Sigma} \mathbf{J} \cdot d\mathbf{S} + \varepsilon_0 \frac{d}{dt} \iint_{\Sigma} \mathbf{E} \cdot d\mathbf{S} \right)$	$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$

Normal conductor

Perfect conductor

Normal conductor vs. perfect conductor

Magnetic fields in a perfect conductor

Magnetic fields in a perfect conductor

Magnetic field in a perfect conductor

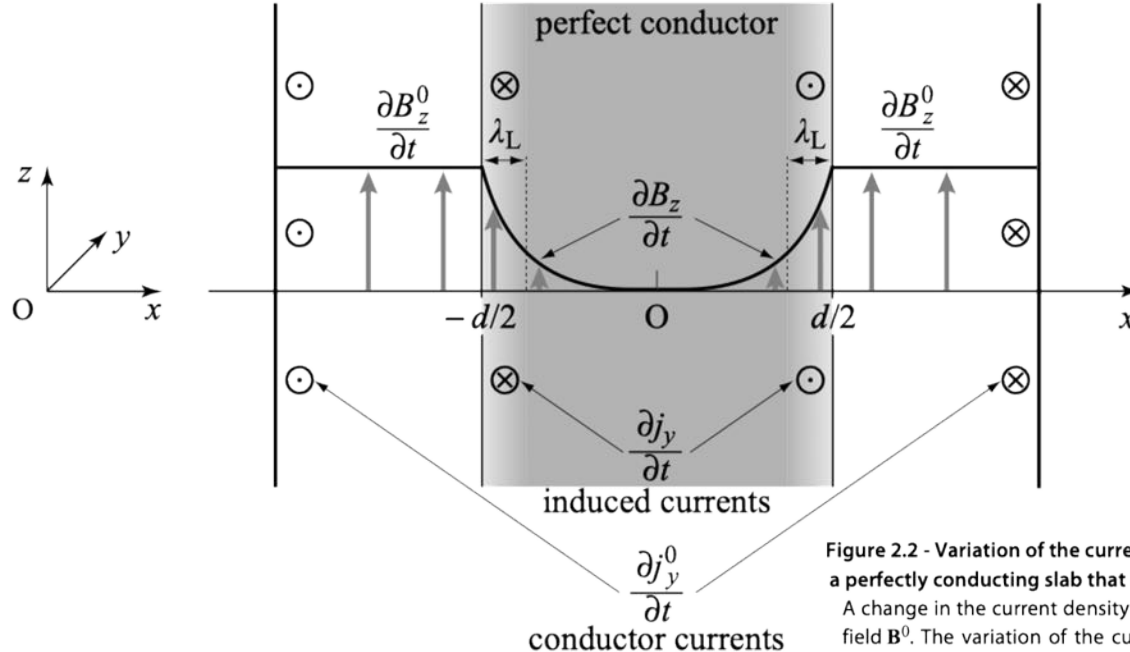
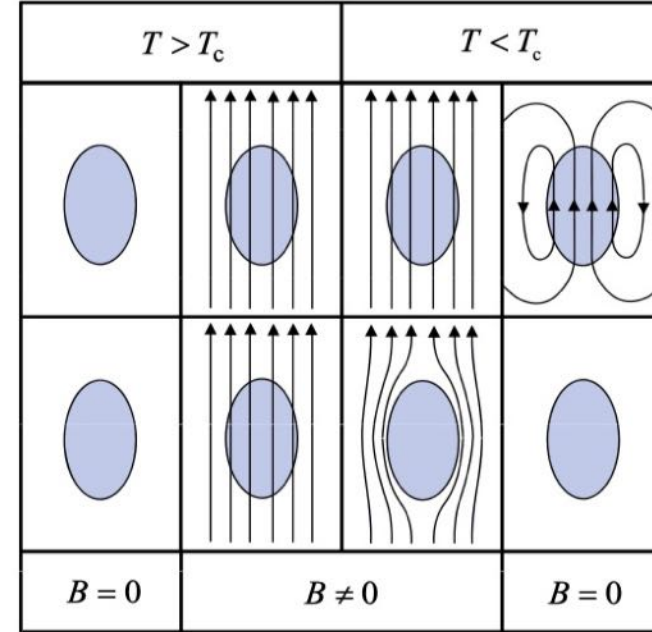
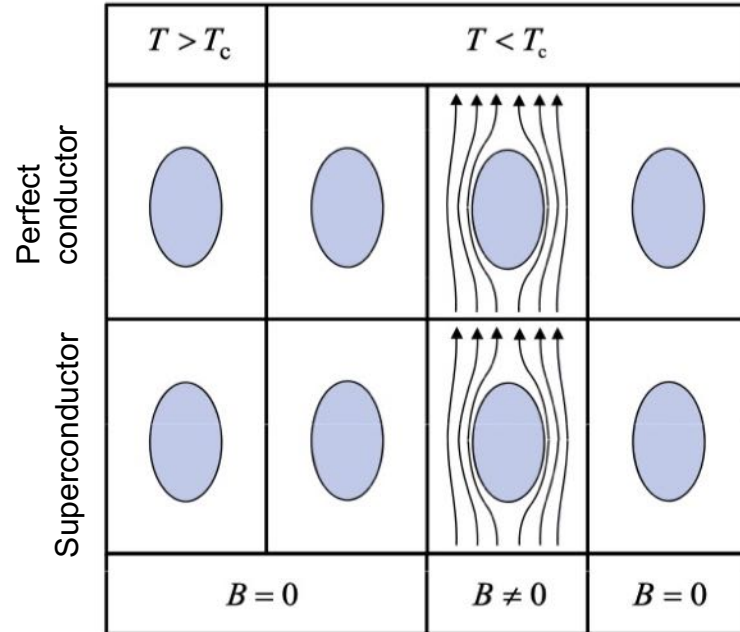


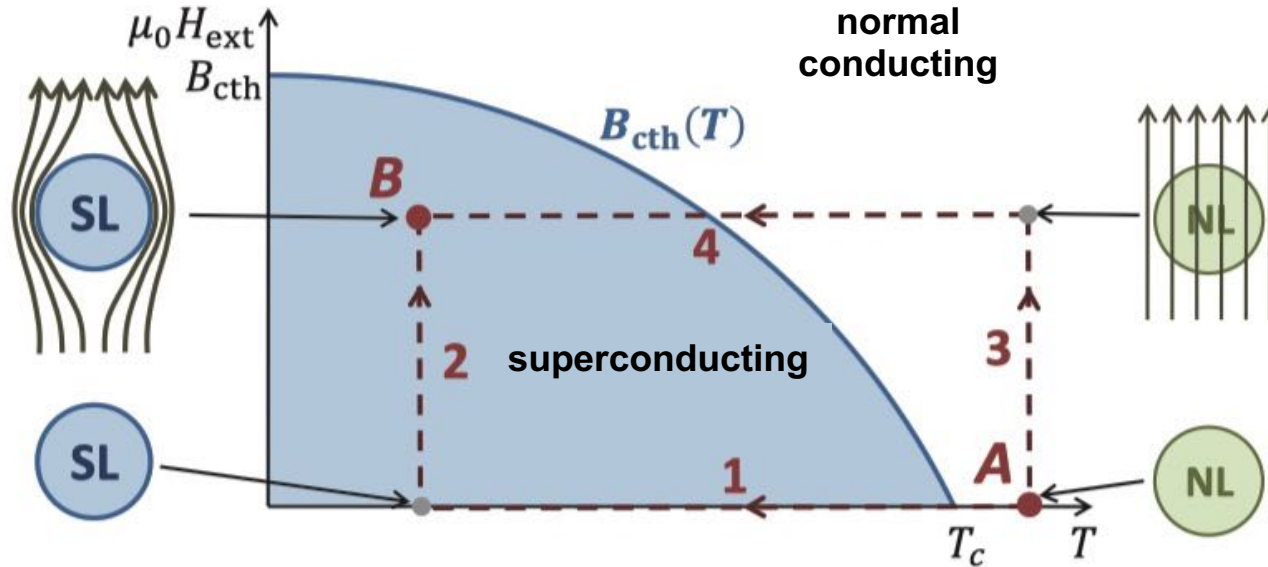
Figure 2.2 - Variation of the current density $\frac{\partial j_y}{\partial t}$ and magnetic field $\frac{\partial B_z}{\partial t}$ inside a perfectly conducting slab that is subject to a time-varying magnetic field $\frac{\partial B^0}{\partial t}$
A change in the current density j^0 on the external layers creates a change in the field B^0 . The variation of the current densities j near the surface of the perfect conductor is that induced by the variation of B^0 . It is such that B stays constant ($\frac{\partial B_z}{\partial t} = 0$) inside the slab except for a transitional region of thickness λ_L .

Reminder: Magnetic field behavior of a perfect conductor and a superconductor



Perfect diamagnetism

B - T -Phase diagram of a superconductor



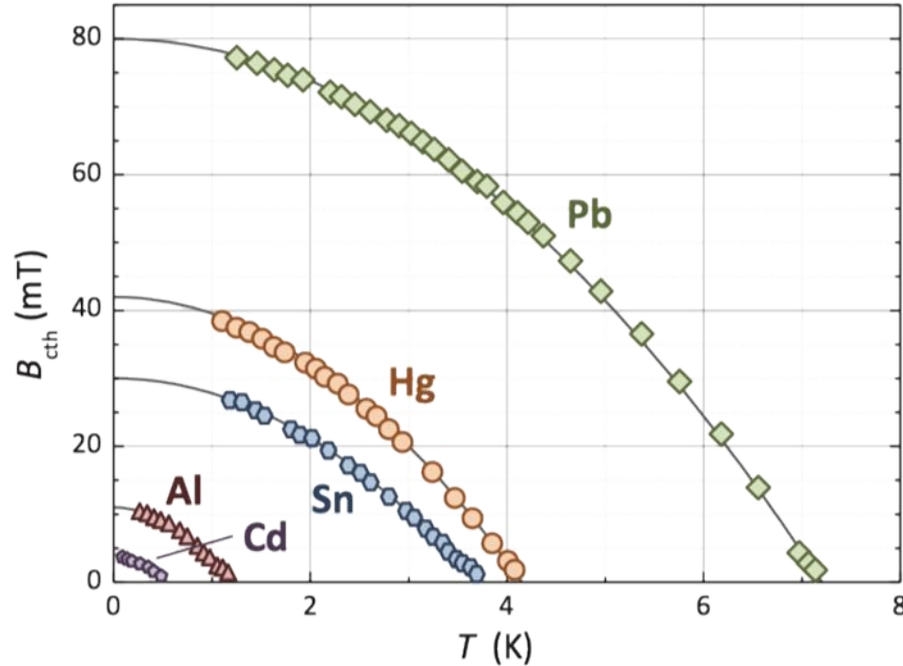
***B-T*-Phase diagram of a superconductor**

***B-T*-Phase diagram of a superconductor**

Critical magnetic field

Critical magnetic field

Temperature dependence of B_{cth}

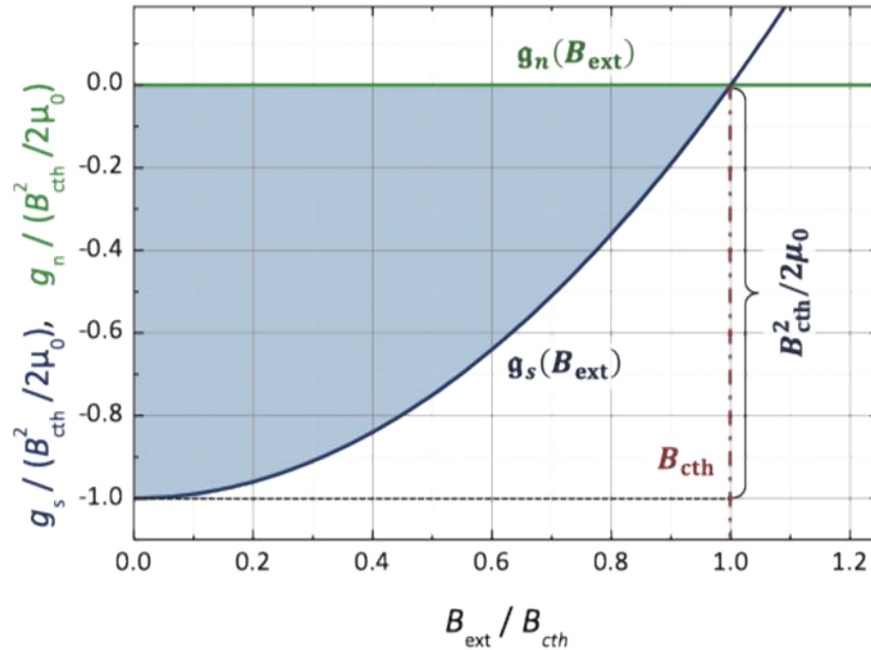


Magnetization of a superconducting sample

Condensation energy

Condensation energy

B-field dependence of Gibbs free energy



London theory, Two-fluid model

London theory, Two-fluid model

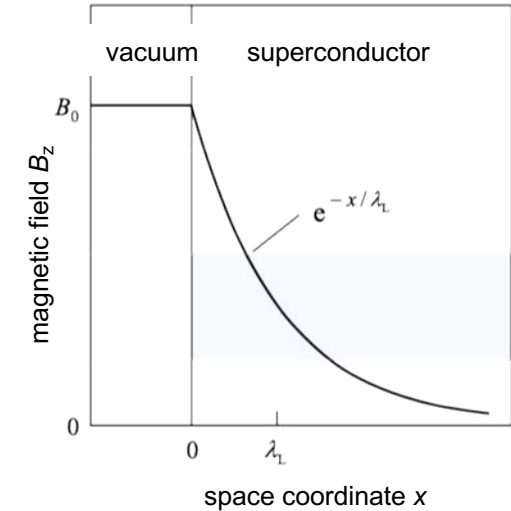
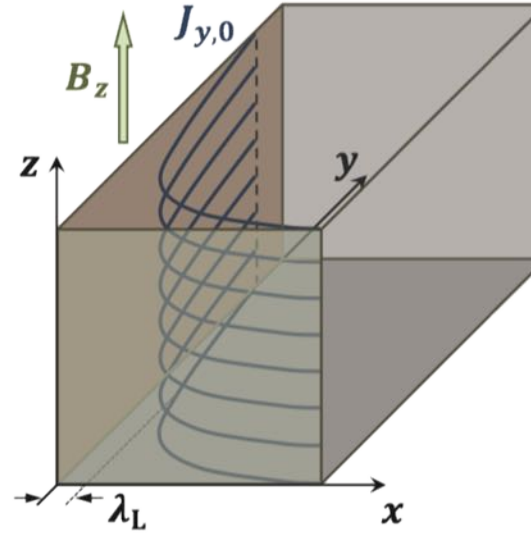
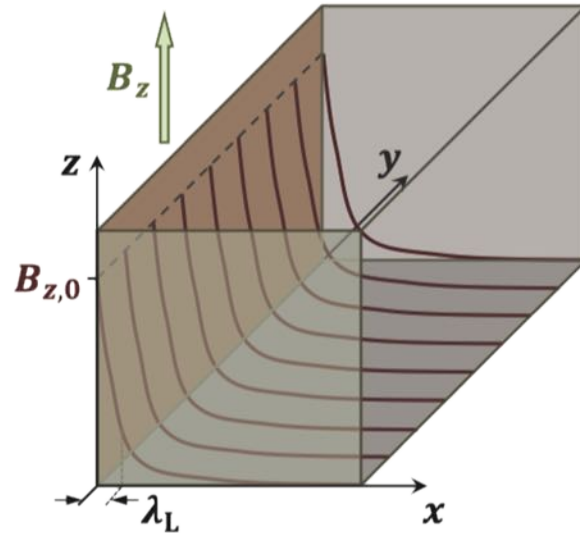
Normal electrons vs. superelectrons

Superelectrons

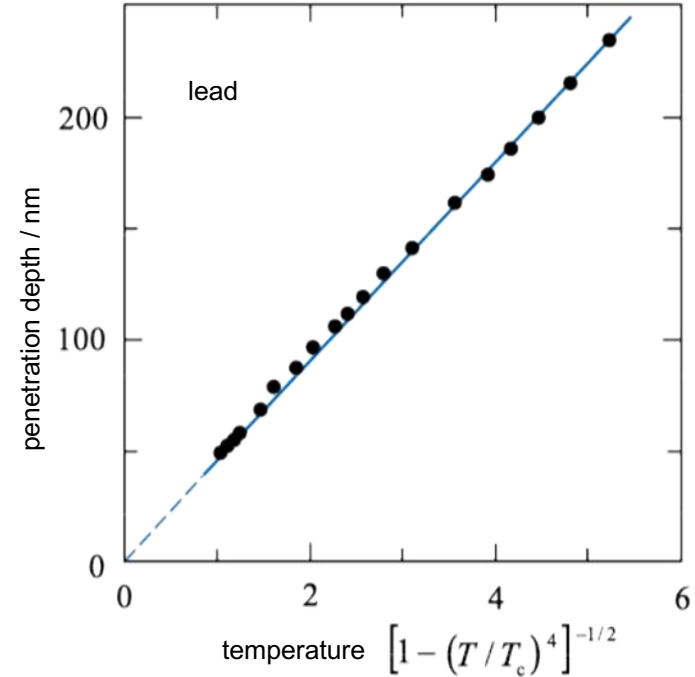
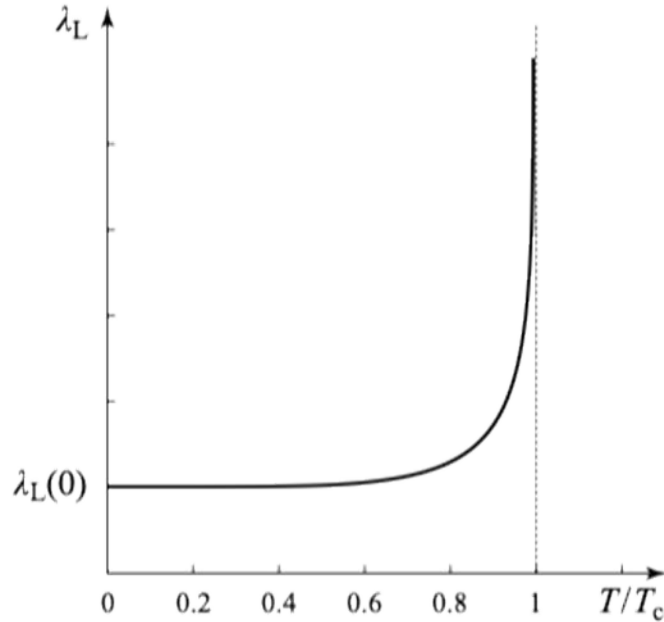
Magnetic field penetration within a superconductor

Magnetic field penetration within a superconductor

Magnetic field penetration within a superconductor



T-dependence of London penetration depth



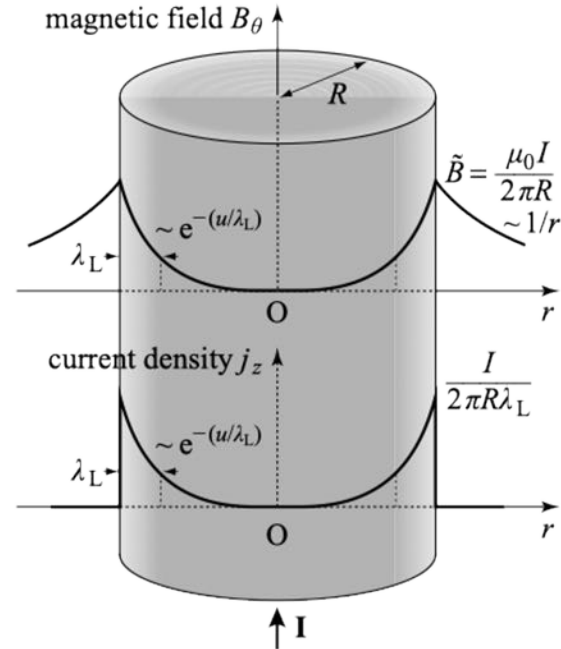
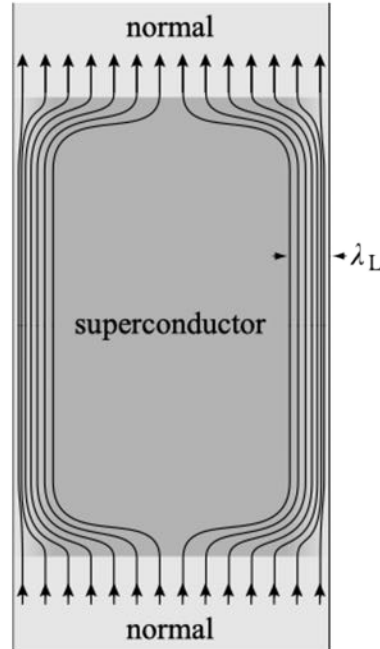
T -dependence of London penetration depth

Two-fluid model revisited

Two-fluid model revisited

Application: Superconducting wires

Current-carrying superconducting wire



Current-carrying superconducting wire

Current-carrying superconducting wire

Critical current / critical current density

Temperature dependences

Phase diagram of a superconductor

