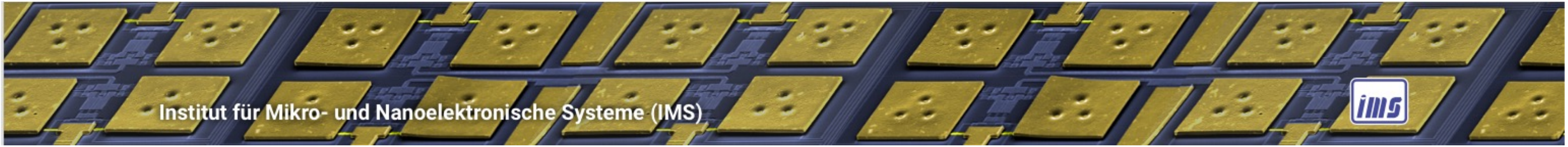
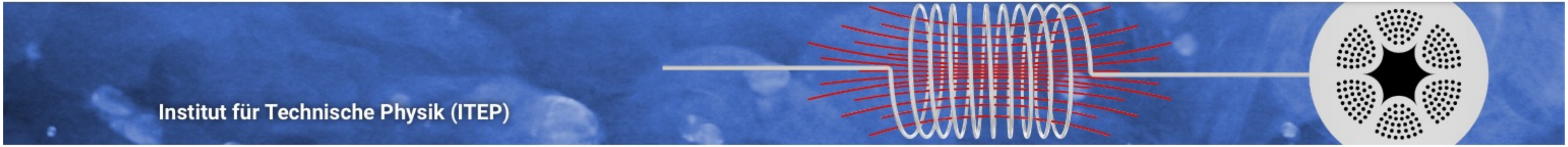
Karlsruher Institut für Technologie

Superconductivity for Engineers

Prof. Dr. Sebastian Kempf, Prof. Dr. Bernhard Holzapfel

Summer term 2021





(Preliminary) Schedule

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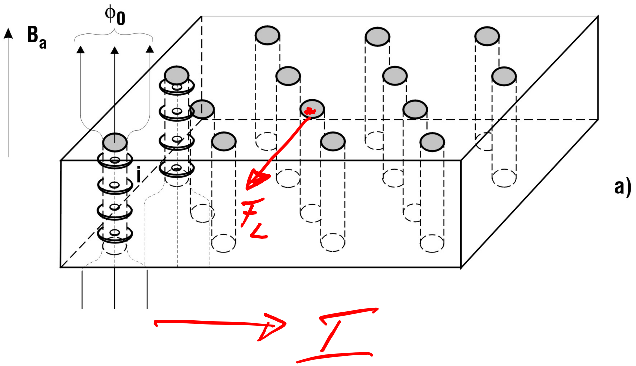
	Day	Date	Lecture / Tutorial	Day	Date	Lecture / Tutorial
1	Mon	21-04-12	Lecture 1 (SK)	Wed	21-04-14	
2	Mon	21-04-19	Lecture 2 (BH)	Wed	21-04-21	
3	Mon	21-04-26	Lecture 3 (SK)	Wed	21-04-28	Tutorial 1 (IMS)
4	Mon	21-05-03	Lecture 4 (SK)	Wed	21-05-05	
5	Mon	21-05-10	Lecture 5 (SK)	Wed	21-05-12	~~Tutorial 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)**	**Type-II superconductors, Current transport**
Lecture 8:	**(BH)**	**Bean Model, Ginzburg-Landau theory**
Lecture 9:	**(BH)**	**Type-I superconductors**
Lecture 10:	**(BH)**	**Type-II superconductors**
Lecture 11:	**(BH)**	**Pinning and superconducting permanent magnets**
Lecture 12:	**(BH)**	**ac-losses, electrical stabilization and thermal aspects**
Lecture 13:	(SK)	Josephson junctions and SQUIDs
Lecture 14:	(SK)	Josephson junctions and SQUIDs

Current transport in ideal type II superconductors

Shubnikov phase



→ Ideal SC = without defects

↳ Lorentz force $\vec{F}_L = \vec{j} \times \vec{B}$ acts on FL

↳ FL will move

↳ dissipation of energy by R

→ No J_c

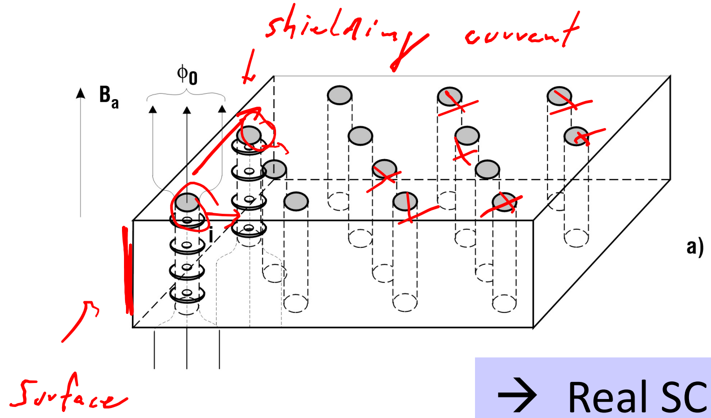
→ Need to pin FL

No dissipation free current transport in ideal type II superconductors in the Shubnikov Phase !!!

Current transport in real type II superconductors

↳ with defects

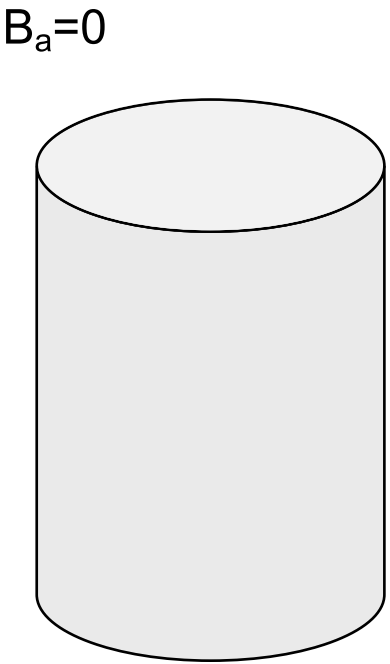
Shubnikov phase



- → Real SC = SC with defects
- → Flux pinning at defects
- → Flux lines move only if current induced Lorentz Force $F_L > F_p$
- → $J_c > 0$
- → Inhomogeneous flux distribution inside SC

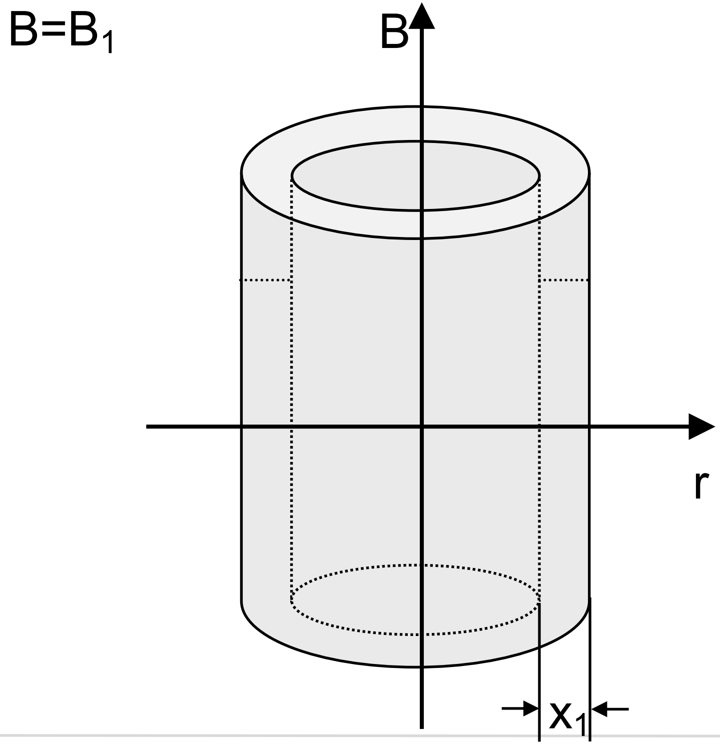
Flux distribution in real type II superconductors

The Bean Model



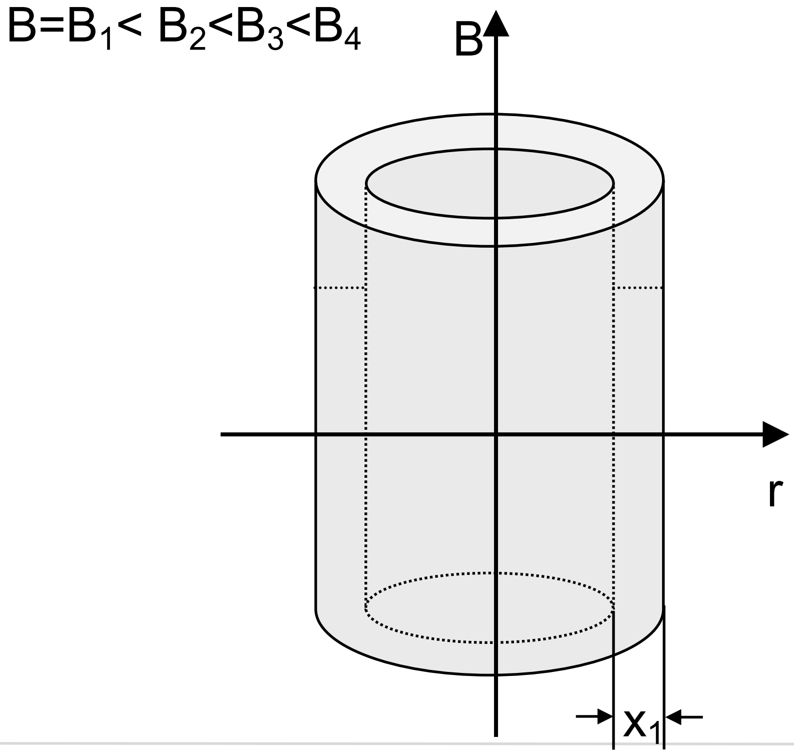
Flux distribution in real type II superconductors

The Bean Model



Flux distribution in real type II superconductors

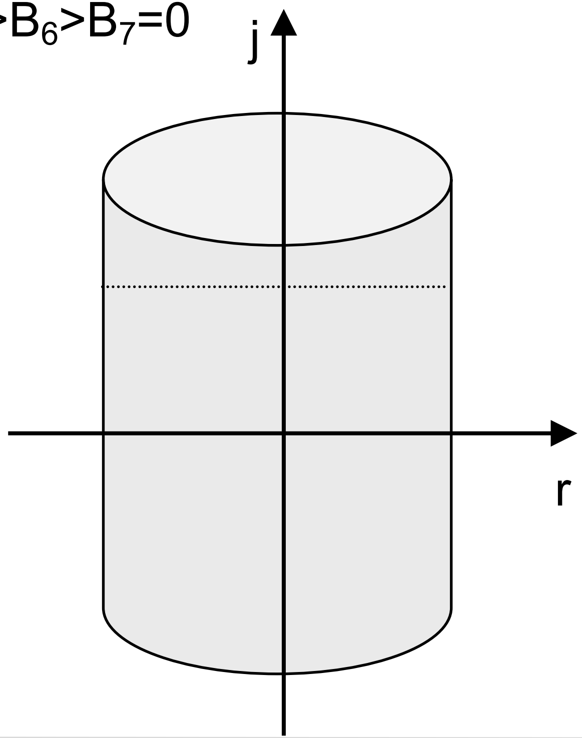
The Bean Model



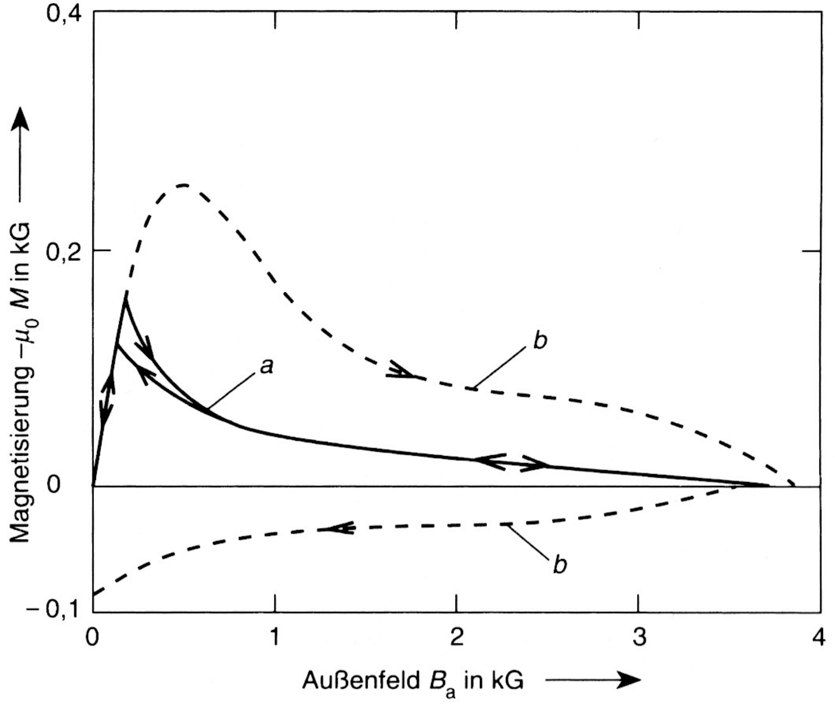
Flux distribution in real type II superconductors

The Bean Model

$B=B_4>B_5>B_6>B_7=0$



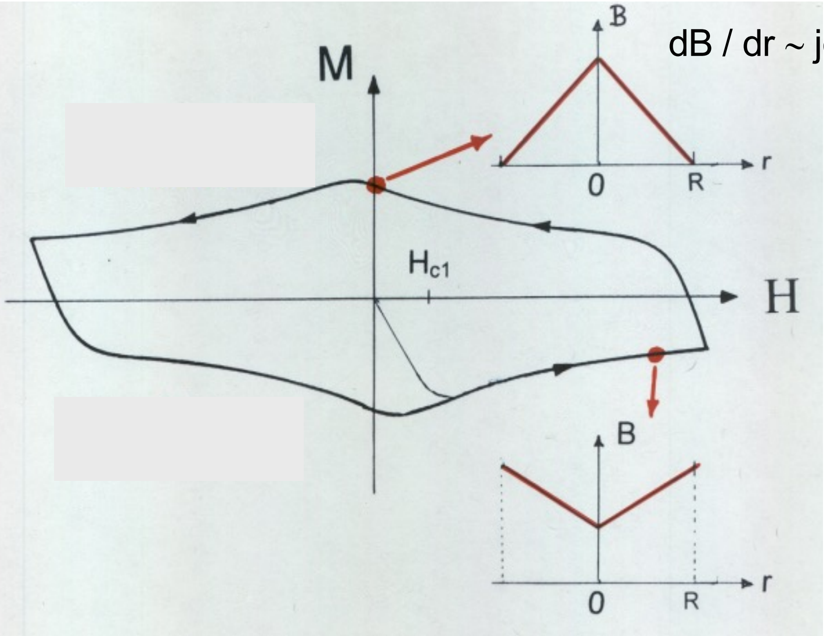
Magnetization of „real“ type II superconductors



a) Annealed
b) With defects

Hysteresis of type II superconductors

Magnetization and flux profile

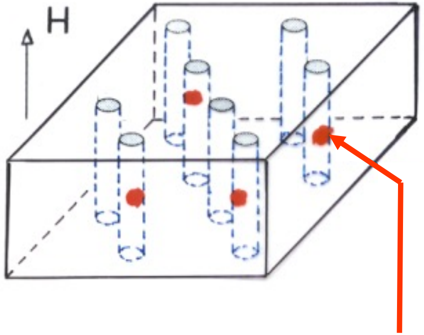


dB / dr ~ jc

$H > H_{c1}$: ⇨ flux penetration

$\Phi_0 = 2*10^{-15}\ Tm^2$

$\xi = 1{,}8\ nm$



Pinning of flux lines by defects (pinningcenter)

Ginzburg-Landau-Theory: General remarks

→ **First published in russian**
V.L. Ginzburg and L.D. Landau, *Zh. Eksp. Teor. Fiz.* **20** (1950) 1064

→ **Appreciated only gradually in the West**

→ **Abrikosov predicted 1957 the flux line lattice based on GL**

→ **Phenomenological theory, no need for microscopic understanding;**
but might be deduced from microscopic theories (form BCS theory by Gorkov in 59)

→ **Also known as Ginzburg-Landau-Abrikosov-Gorkov (GLAG) theory**

→ **Can deal with non-uniform superconducting states**
(Shubnikov phase - flux distribution; proximity effect; fluctuations)

→ **Based on an earlier theory of Landau on phase transitions in general**

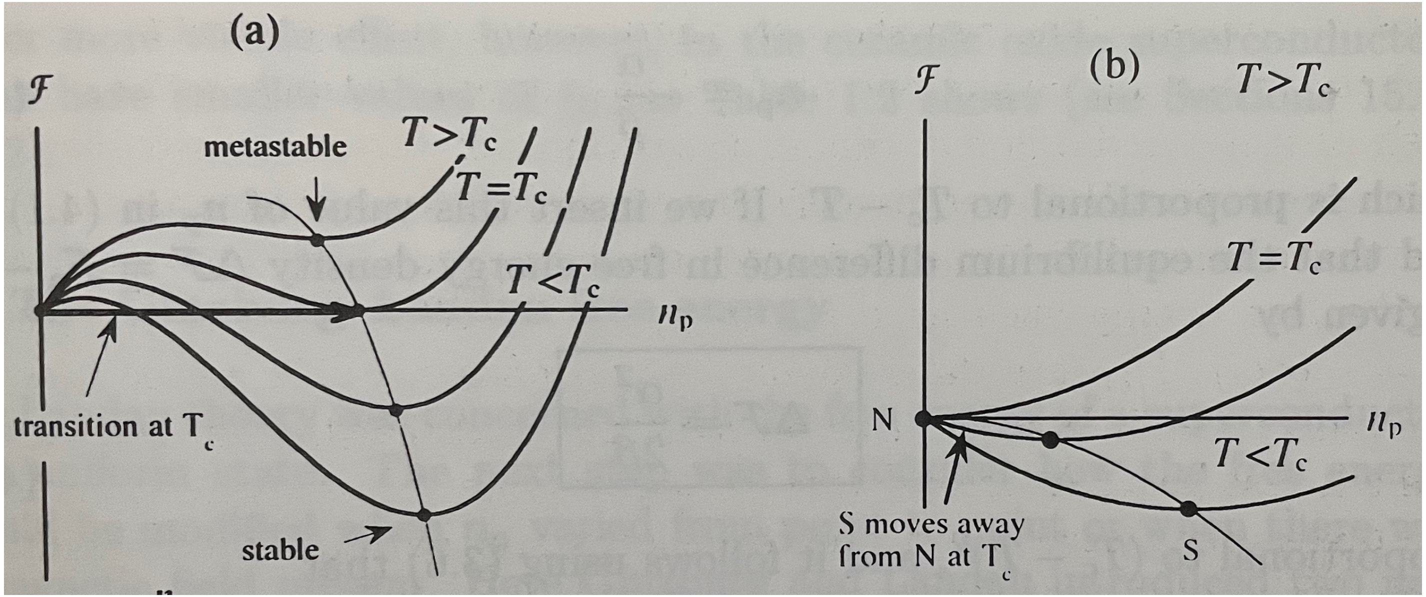
Landau-Theory of phase transitions

→ **Phase transition is characterized by the onset of an „order parameter“ during variation of temperature or other variables**

→ **For superconductivity: macroscopic wave function is complex order parameter**

→ **The relevant thermodynamic function depend on the order parameter and the form of this function determines the degree of the phase transition**

Landau-Theory of phase transitions



Landau-Theory of phase transitions

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→ For a second order phase transition $\mathcal{F}(n_p, T)$ is analytic, shows a minimum at T_c and n_p=0 and can be expanded around this point in powers of n_p and (T-T_c)

→ GLAG is valid around T_c !

$$\mathcal{F}(n_p, T) = \mathcal{F}_n(T) + \alpha(T) n_p + \tfrac{1}{2}\beta(T) {n_p}^2 + \ldots.$$

$$\Delta\mathcal{F} = \mathcal{F}_n - F_s = \frac{\alpha^2}{2\beta}$$

Minimum of $\mathcal{F}(n_p, T)$:

$$d\mathcal{F}/dn_p = 0 \rightarrow \quad \alpha + \beta n_p = 0 \quad d.h.\ \ n_p = -\tfrac{\alpha}{\beta}$$

$$B_c(T) = -\sqrt{\frac{\mu_0}{\beta}}\,\alpha(T)$$