Pinning of Vortices in Type II Superconductors

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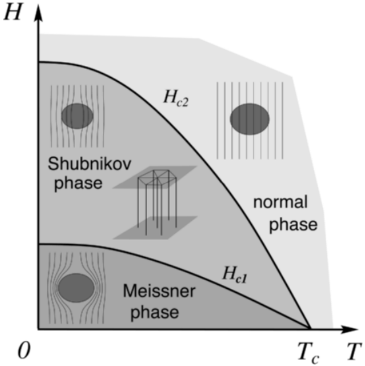
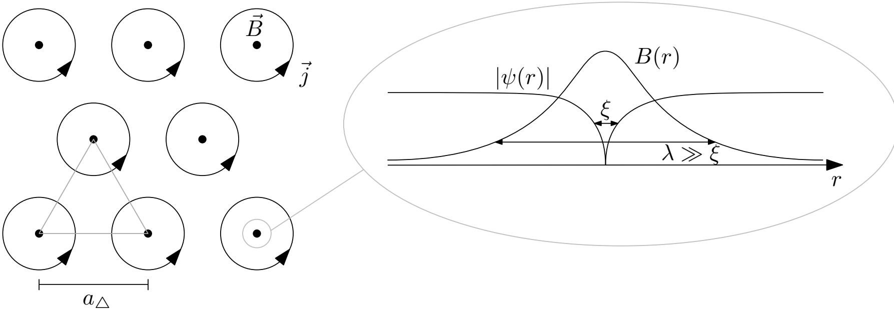
Type II superconductors



- 1935: vortex phase observed experimentally in 1935 by Lev Shubnikov
- 1957 theoretical model by Alexei Aborikosov (Nobel prize in 2003 together with V.L. Ginzburg)
- Most hight T_c superconductors are type II

Vortex phase

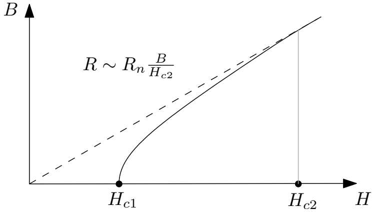
- The most stable configuration is the triangular lattice

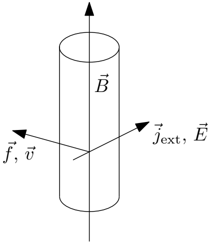


- $a_\triangle \simeq 1.075 \left(\frac{\phi_0}{B}\right)^{1/2}$
- ξ is comparable to the size of single unit cell ($\xi \simeq 0.4$nm in $\mathrm{YBa_2Cu_3O_{7-x}}$)

Onset of resistance

- Ideal type II superconductor where vortices are free to move develops resistance.

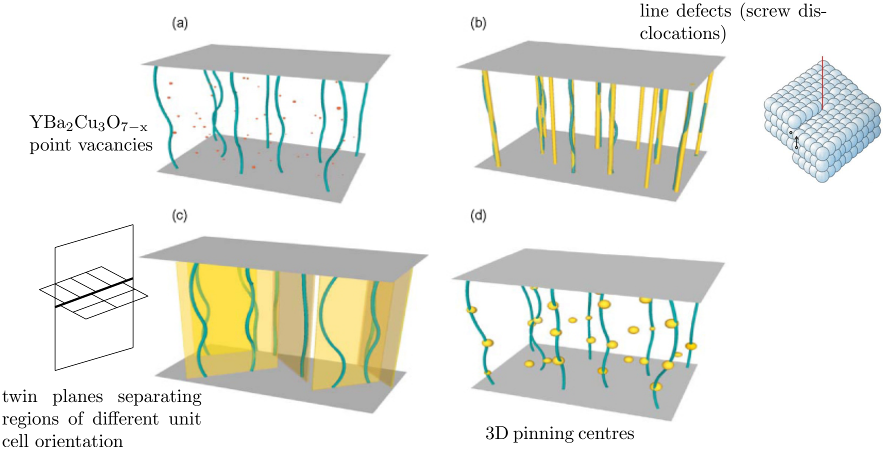




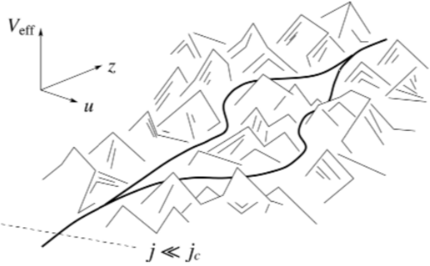
- dissipation $\sim \boldsymbol{j} \cdot \boldsymbol{E}$
- If vortices are pinned, they do not move until we reach a critical current j_c.

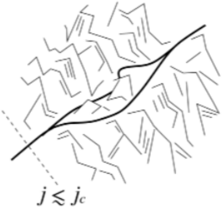
Pinning

- Real materials are not perfect superconductors ⇒ vortices of magnetic field are attracted to the local pinning centres



Flux creep

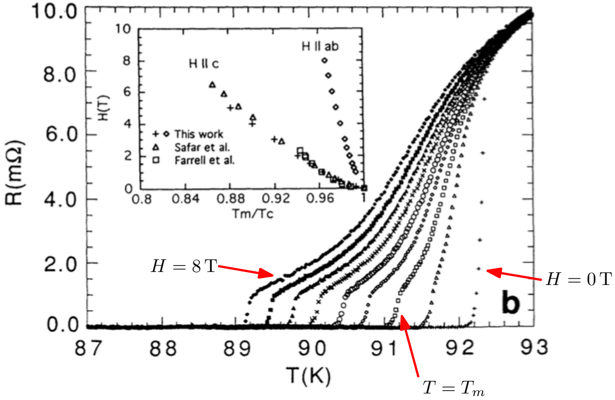




$$V_{\text{eff}} = V - fu$$

- jump rate $\propto \mathrm{e}^{-\Delta F_0/T}$
- small currents: vortices are ‘locked’ in the valleys and jumps are rare
- large enough currents give rise to the critical force: the potential landscape becomes tilted and jumps are more frequent $\Rightarrow$ sudden increase in resistance

Resistance in the presence of pinning



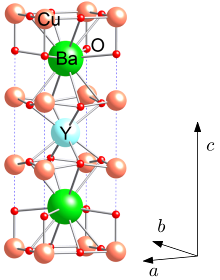
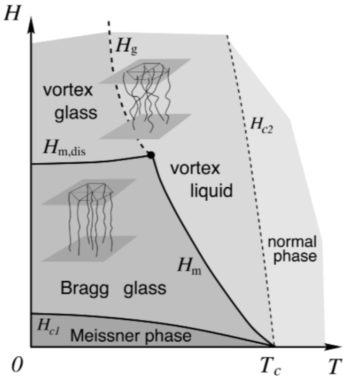


Figure 1: Resistive transition in $\mathrm{YBa_2Cu_3O_{7-x}}$ crystal. Various magnetic fields applied are parallel to *c*-axis[2]

[2] W. Kwok et al., Phys. Rev. Lett. 69, 3370 (1992)

Phases of the vortex lattice

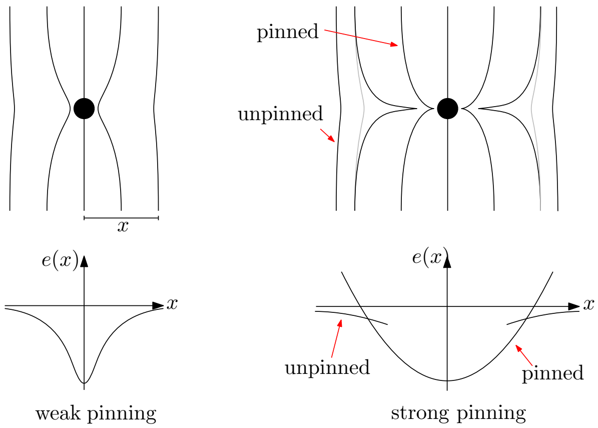
- competition between elasticity, disorder and thermal fluctuations



- glass phase: barriers diverge as $j \to 0$ and inhibit vortex motion $\Rightarrow$ recover 'genuine' superconductor with $\rho \to 0$
- disorder in the vortex glass phase is so strong that it destroys the vortex lattice structure

Pinning mechanism: weak vs. strong pinning

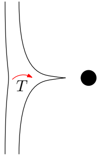
- Discussion above is related to the collective action of many ‘weak’ pins



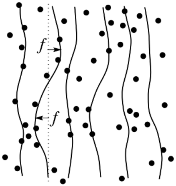
- Strong pins act individually on the vortices. At certain regions, there are bistable solutions with pinned and unpinned vortices.

Research tasks in the strong pinning theory

- Thermal excitations in strong pinning theory



- Collective action of strong pins.



Thank you for your attention.

Resources

G. Blatter, D. Geshenkbein: Vortex Matter. In Superconductivity, Springer 2008.

- General review of vortex matter phases in the introduction.
- The origin of strong pinning and bistable solutions is discussed in ch. 12.8.
- The general discussion of the glass phases can be found in the beginning of ch. 12.12

Introduction to Superconductivity (Tinkham).

- Flux creep is discussed in ch. 5.7
- Flux motion and the effect of pinning in high-T_c superconductors is discussed further in ch. 9.4 and following.