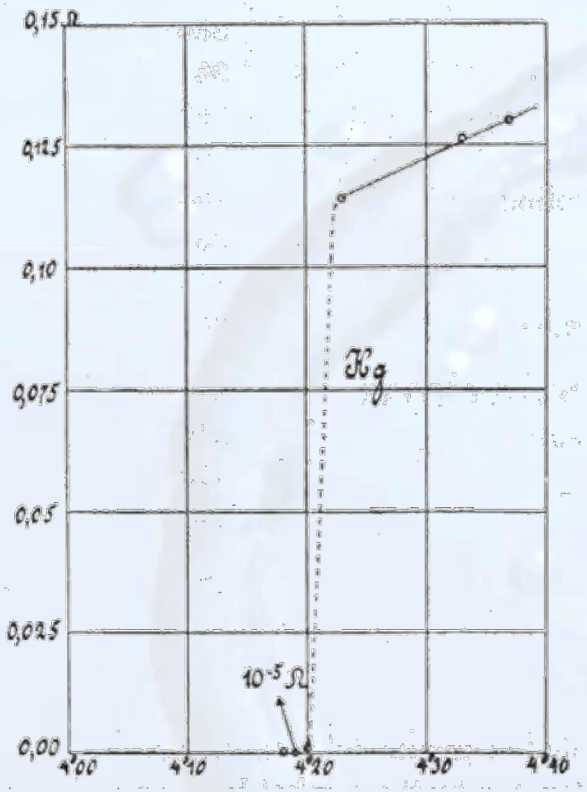
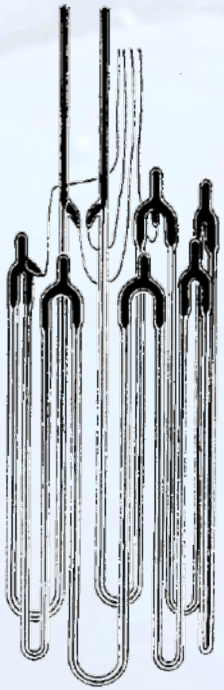
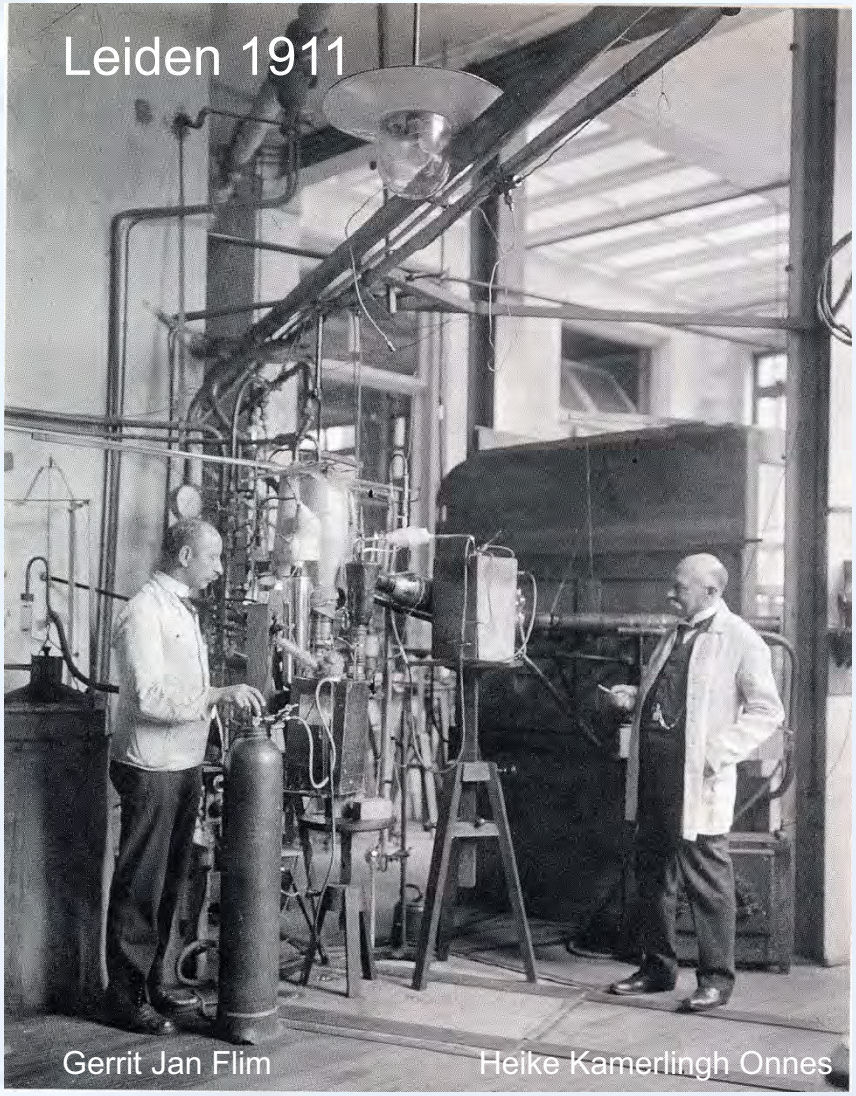
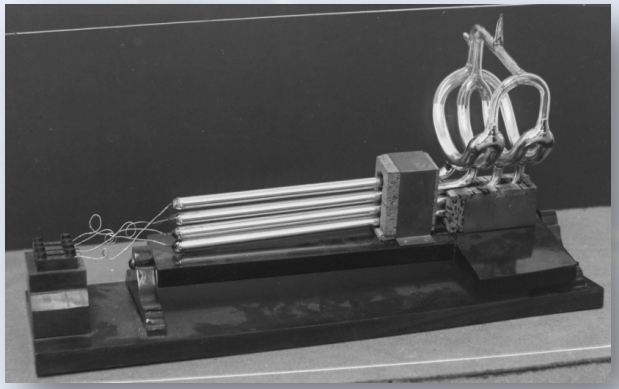
10. Superconductivity

23 May 1911









10. Superconductivity

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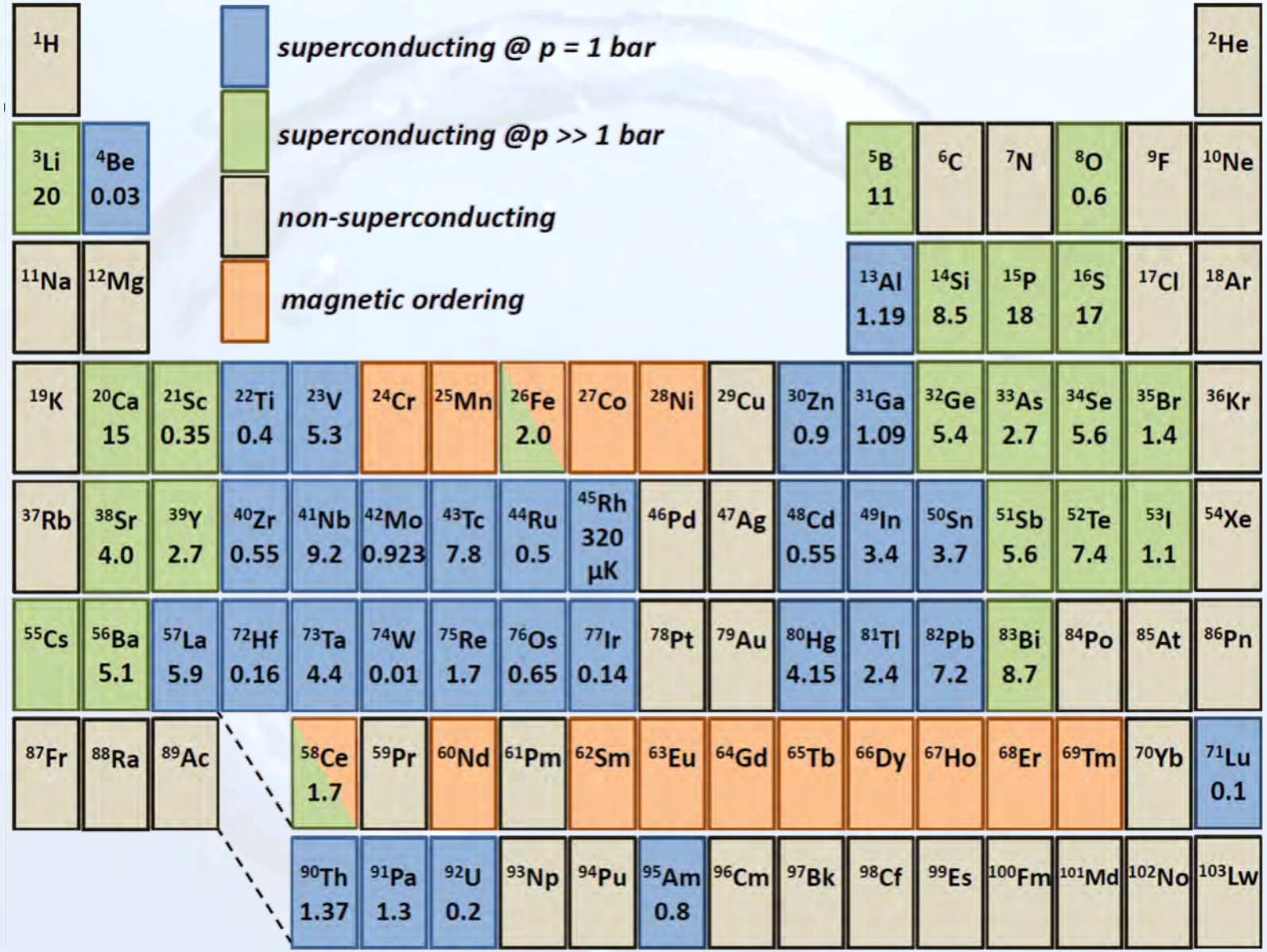
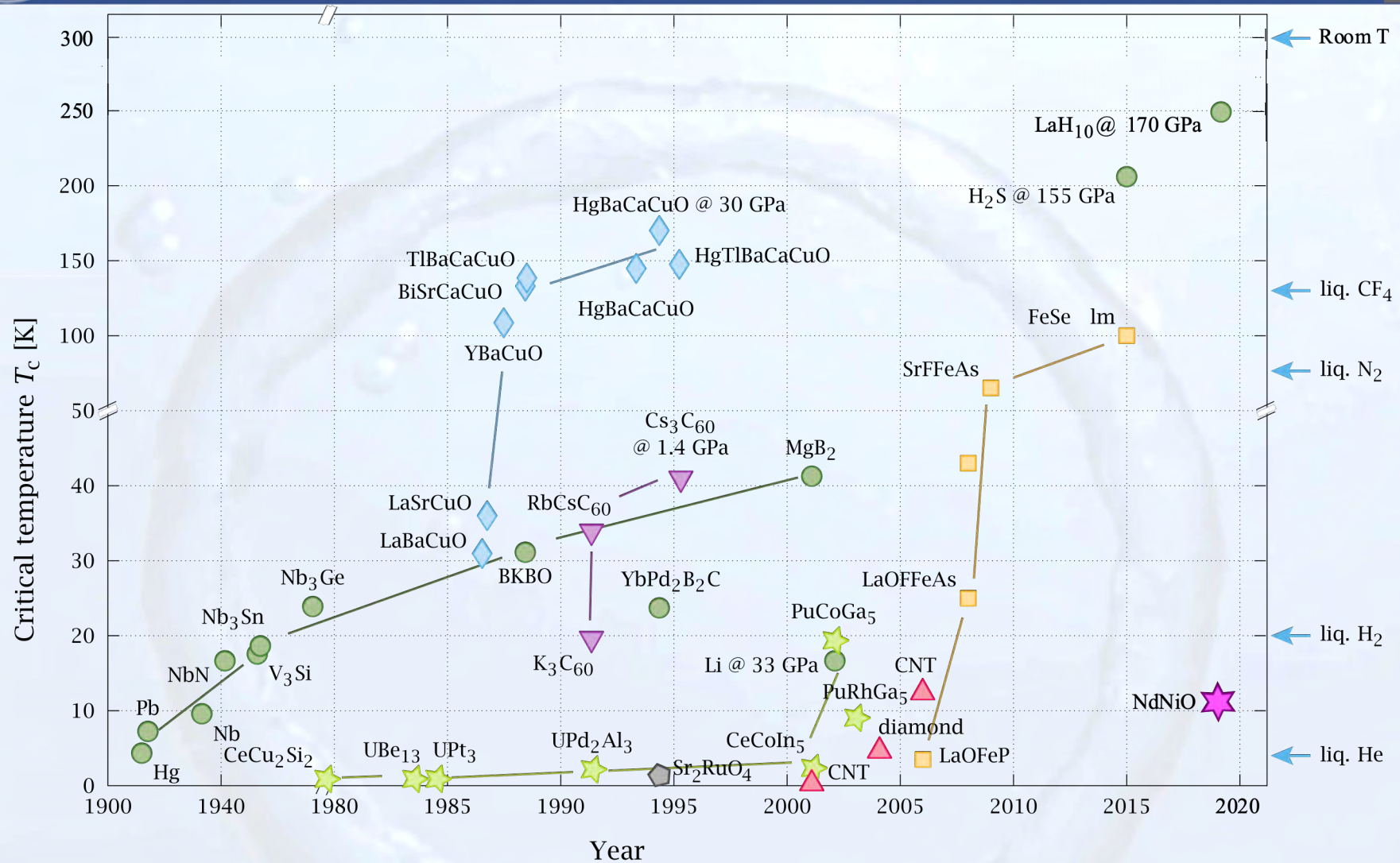


10. Superconductivity

Observations regarding superconductivity

- small atomic volume appears to favor superconductivity
- metals, semi-metals, semi-conductors (highly doped)
- not superconducting: good conductors Ag, Au, Cu, K, …. and magnetic systems Fe, Ni, Co, …
- impurities are unimportant, except magnetic impurities
- structural order is unimportant: single crystals, poly crystals, alloys, amorphous solids
- transition temperatures are material dependent and spread over a wide range
- sufficiently large magnetic fields destroy superconductivity

10. Superconductivity



BCS

Cuprate

Iron-pnictogen-based

Fullerene

Heavy Fermion

Carbon-allotrope

Nickel-based

Superconductors in magnetic fields

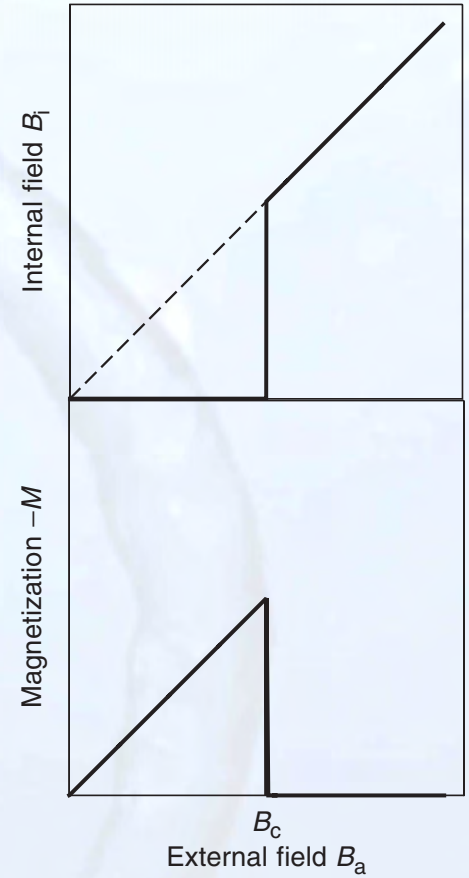
Type-I superconductors (pure metals like Pb, Hg, In, Al, …

$B < B_c$

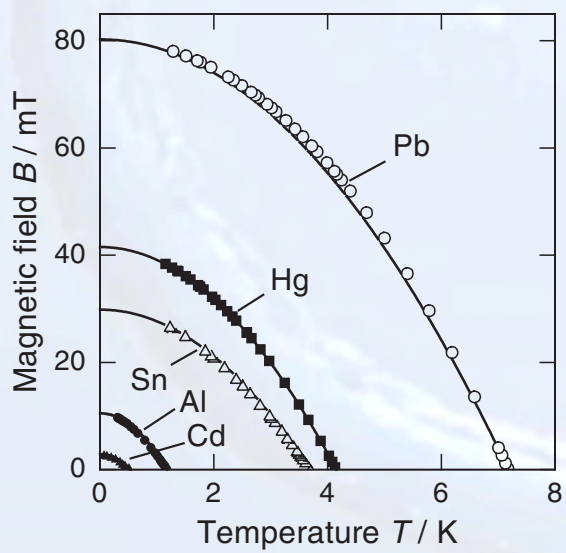
field expelled: $B_i = B_a + \mu_0 M = 0$ Meißner phase

$\longrightarrow M = -B_a/\mu_0$

$\longrightarrow \chi = \frac{\mu_0 M}{B_a} = -1$ ← ideal diamagnet



$B_c(T)$



- critical fields are low (mT)
- empirical relation for $B_c(T)$

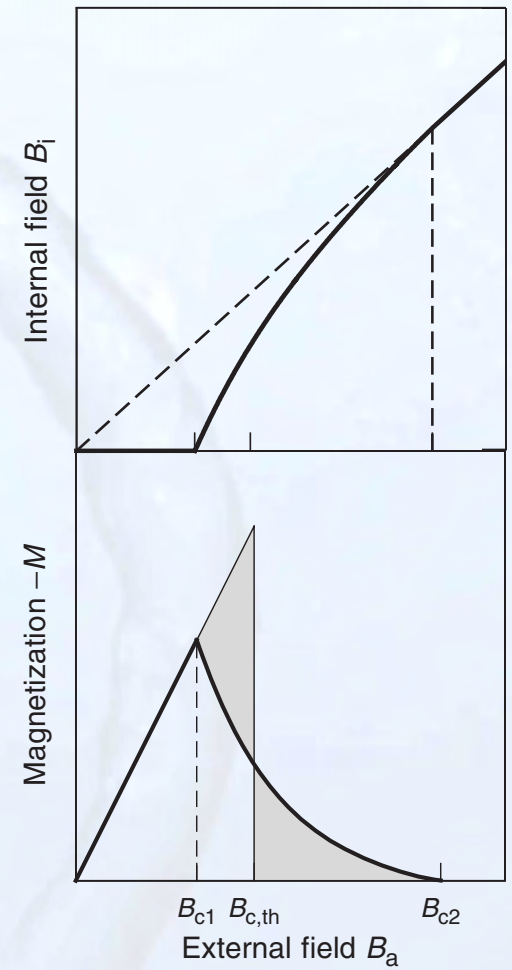
$$B_c(T) = B_c(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

10. Superconductivity

Type-II superconductors (alloys, metallic glasses, high-T_c sc, …)

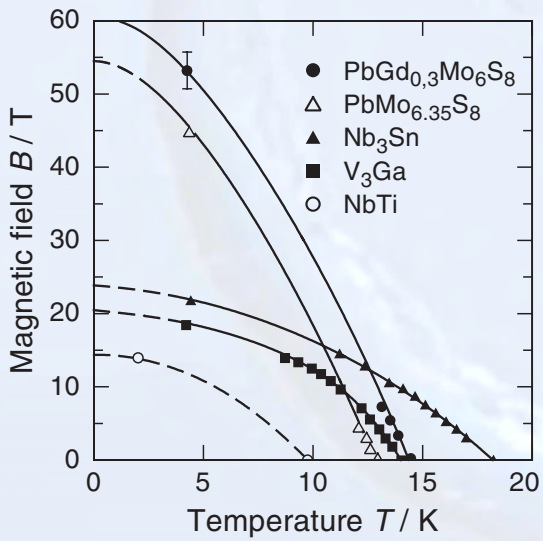
$B < B_{c1}$ Meißner phase: field fully expelled

$B_{c1} < B < B_{c2}$ Subnikov phase: magnetic flux in form of vortices penetrate into sample



Important: B_{c2} can be much higher than B_{c1}

temperature dependence of critical field

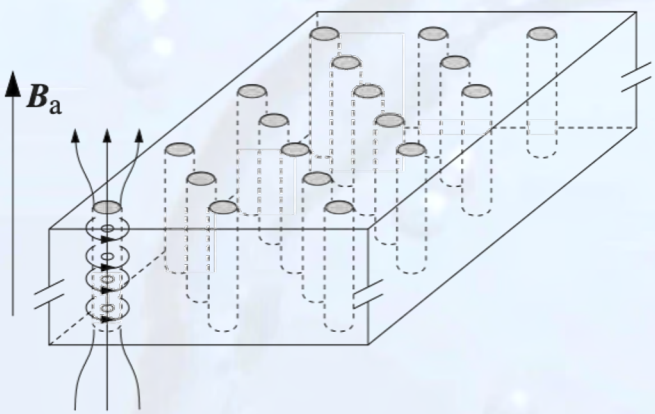


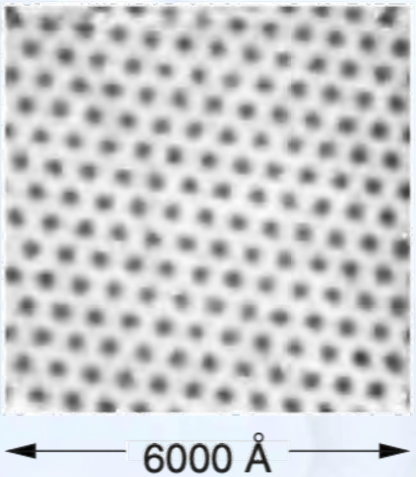
critical field B_{c2} at $T = 0$ ⟶ above 10 T

10. Superconductivity

Abrikosov lattice

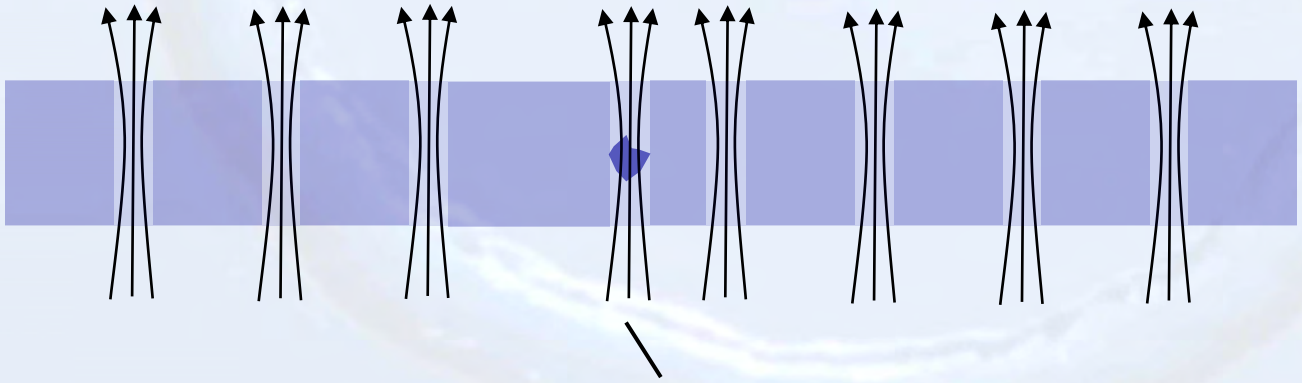
in perfect crystals (free of inclusions and crystal defects) formation of a regular lattice (pattern)





STM image
$NbSe_2$ at 1.8 K
T_c (B = 0) = 7.2 K

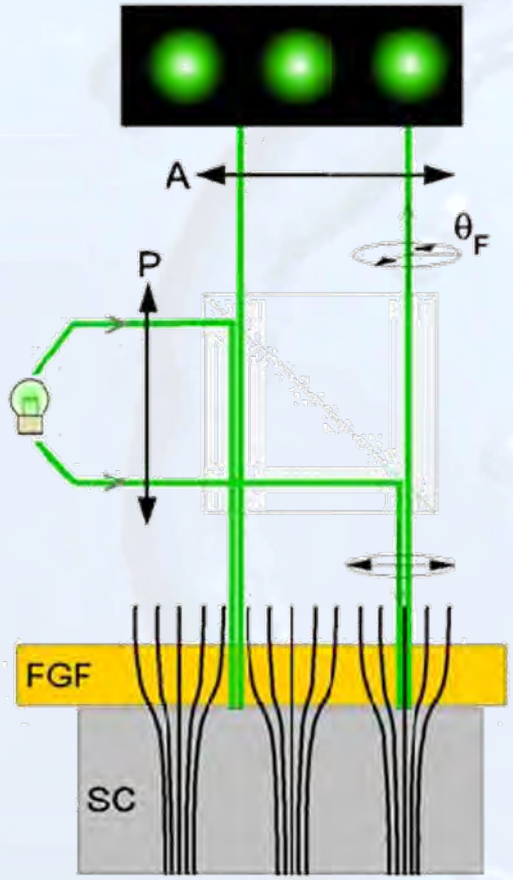
pinning effect: inclusions in crystals lead to pinning of vortex lines

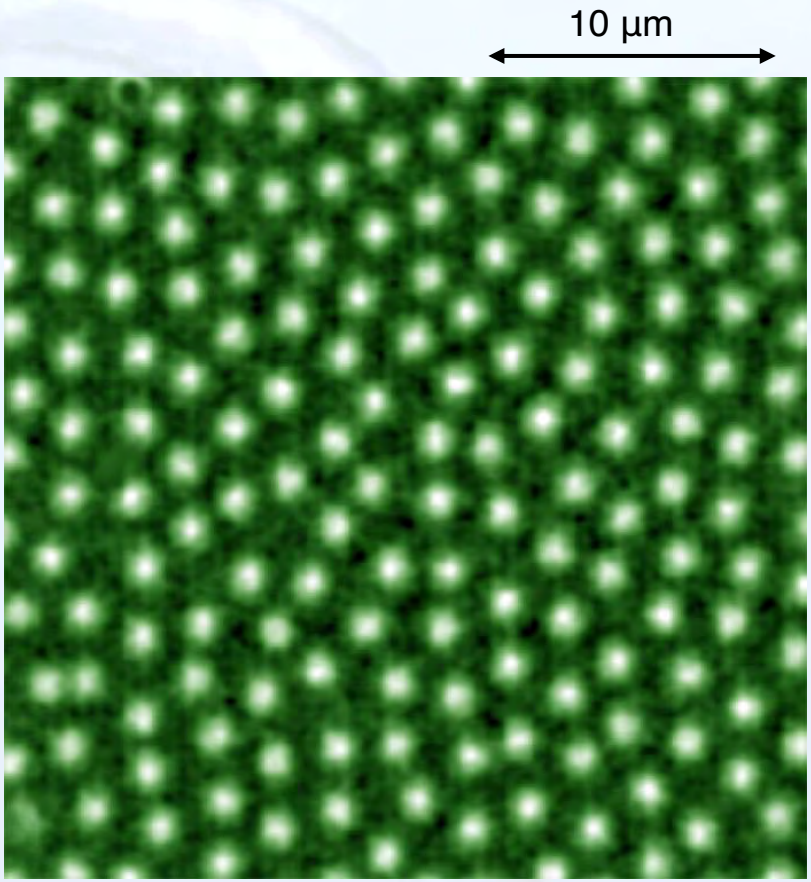


to move a pinned vortex one needs to "pay" the condensation energy

10. Superconductivity

magneto-optical image of vortex Lines

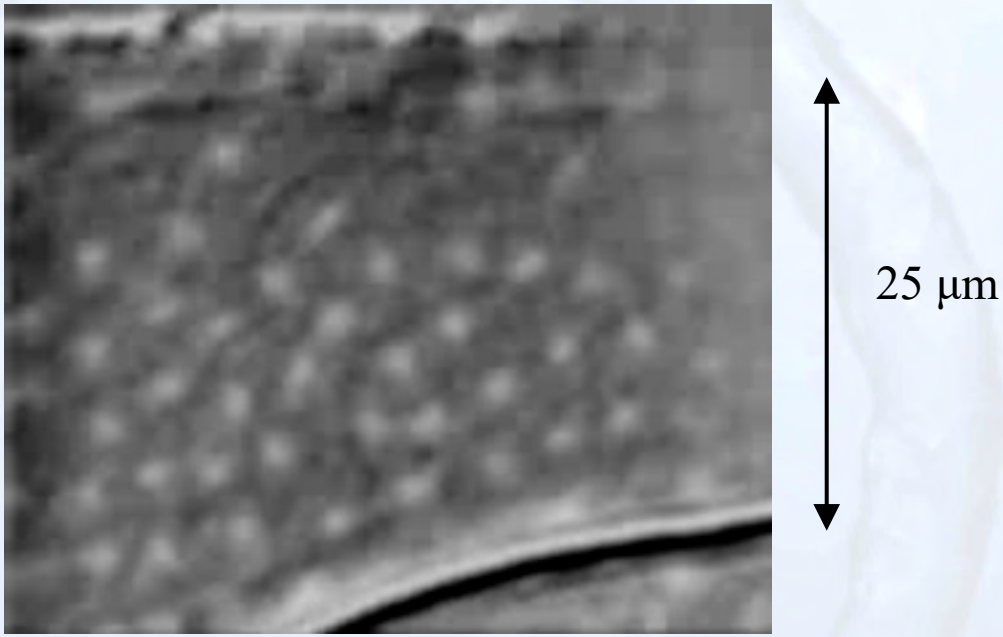




$NbSe_2$ T= 4.3 K, B = 0.3 mT

10. Superconductivity

penetration of magnetic flux into a superconductor



$NbSe_2$

Meißner-Ochsenfeld effect

comparison of ideal conductor and superconductor

Faraday law $\oint \boldsymbol{\mathcal{E}} \cdot \mathrm{d}\boldsymbol{s} = -\partial\Phi/\partial t$