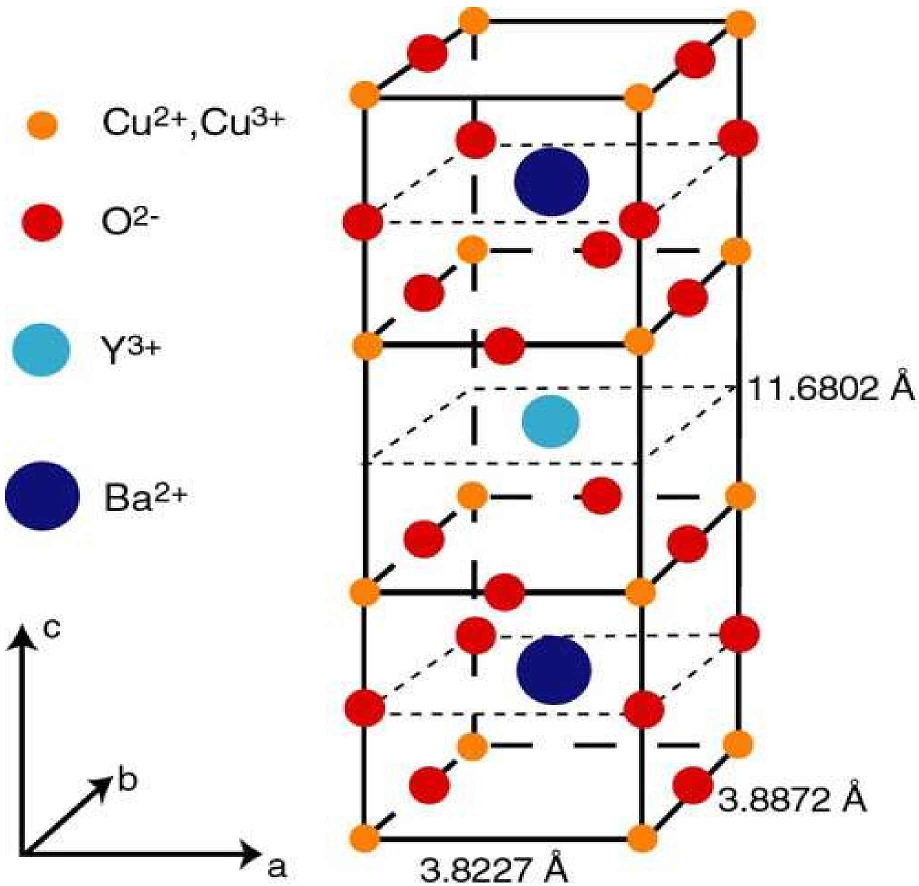
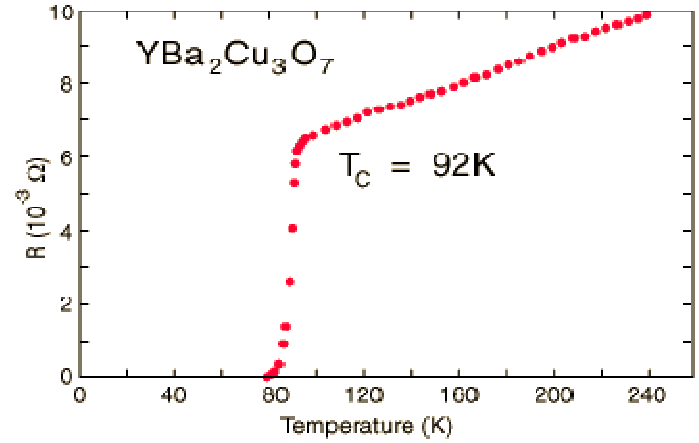
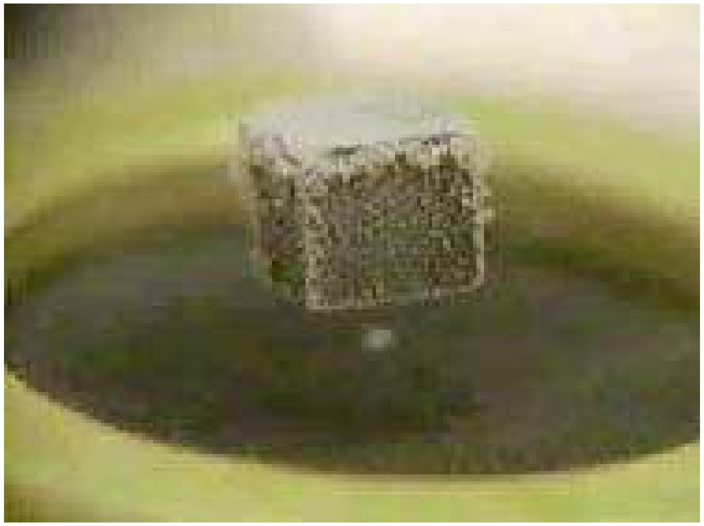
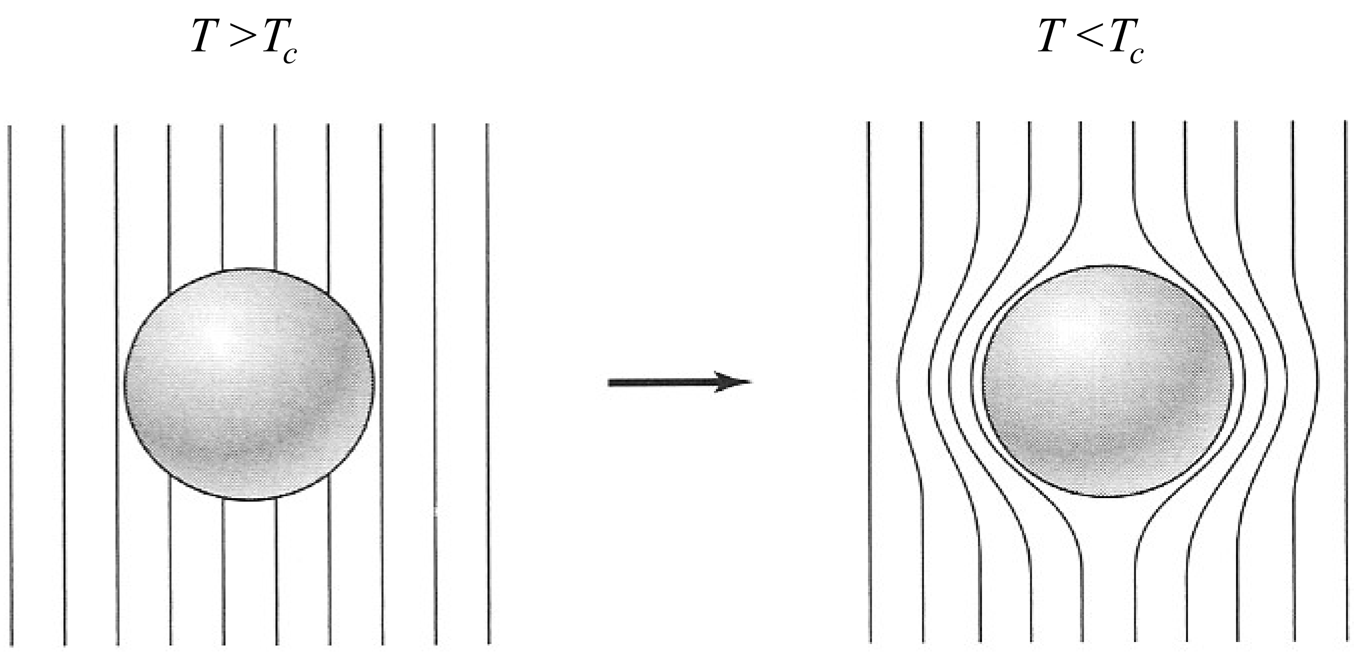
$YBa_2Cu_3O_x$


Cu2+,Cu3+
O2-
Y3+
Ba2+
c
b
a
11.6802 Å
3.8872 Å
3.8227 Å


YBa2Cu3O7
Tc = 92K
R (10^-3 Ω)
Temperature (K)
0
2
4
6
8
10
0
40
80
120
160
200
240



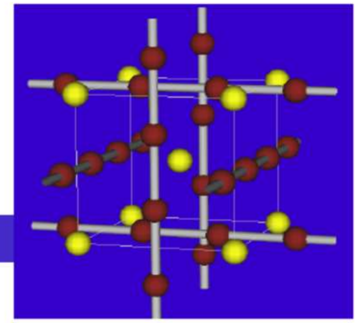
Meissner effect

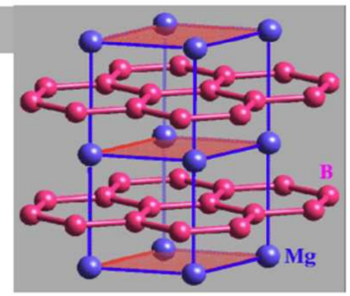


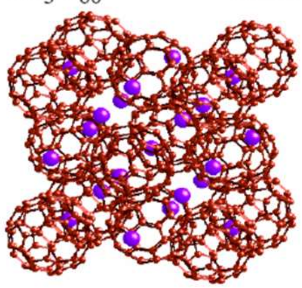
Superconductors are perfect diamagnets at low fields.
$B = 0$ inside a bulk superconductor.

Superconductors are used for magnetic shielding.

	Material	T_c
• Legierung:	NbTi	9,6 K
• Verbindungen:	NbN	16,0 K
Borocarbide:	$(Lu/Y)Ni_2B_2C$	16,0 K
"A15"-Strukturen:	Nb_3Sn	18,0 K
(= β-Wolfram-Struktur)	Nb_3Al	18,7 K
	Nb_3Ge	22,5 K
neu:	MgB_2	39 K
Fullerene:	Cs_2RbC_{60}	33 K
+ Druck 15 kbar:	Cs_3C_{60}	40 K

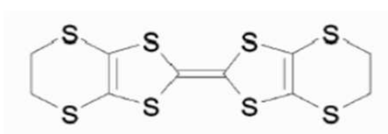


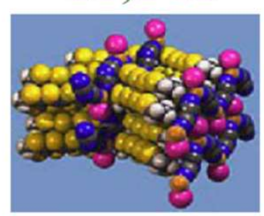




Organische Supraleiter:

$(BEDT\text{-}TTF)_2Cu[N(CN)_2]Br$ 11,2 K





Polymere

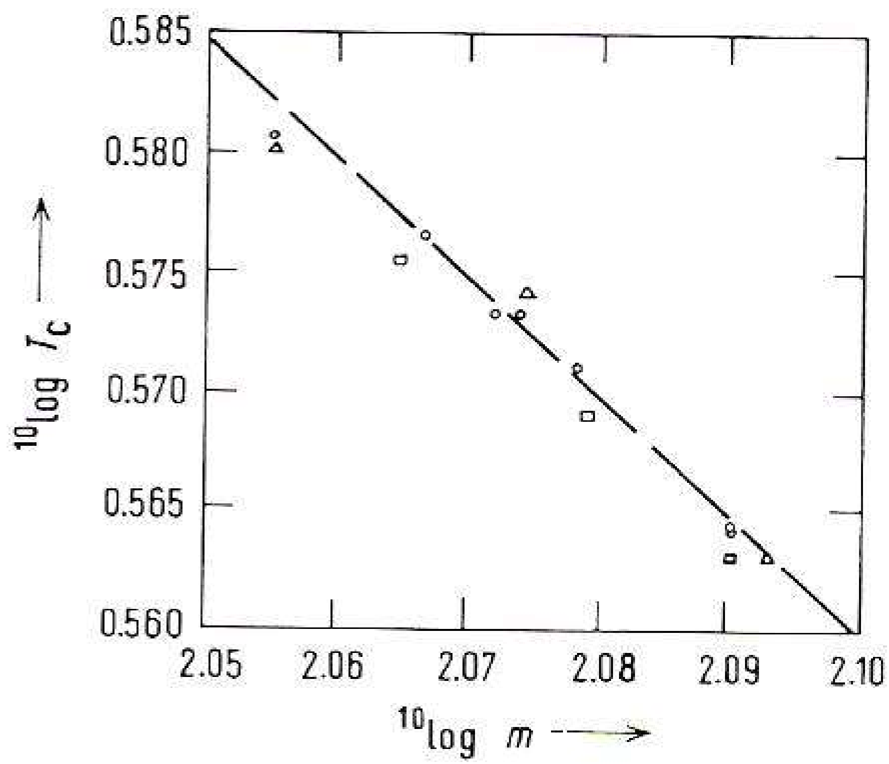
hochdotierte Halbleiter

http://www.wmi.badw.de/teaching/Lecturenotes/index.html

Compound	T_c, in K	Compound	T_c, in K
Nb_3Sn	18.05	V_3Ga	16.5
Nb_3Ge	23.2	V_3Si	17.1
Nb_3Al	17.5	$YBa_2Cu_3O_{6.9}$	90.0
NbN	16.0	Rb_2CsC_{60}	31.3
K_3C_{60}	19.2	MgB_2	39.0

$BaPb_{0.75}Bi_{0.25}O_3$	$T_c = 12$ K	[BPBO]
$La_{1.85}Ba_{0.15}CuO_4$	$T_c = 36$ K	[LBCO]
$YBa_2Cu_3O_7$	$T_c = 90$ K	[YBCO]
$Tl_2Ba_2Ca_2Cu_3O_{10}$	$T_c = 120$ K	[TBCO]
$Hg_{0.8}Tl_{0.2}Ba_2Ca_2Cu_3O_{8.33}$	$T_c = 138$ K	
$(Sn_5In)Ba_4Ca_2Cu_{10}O_y$	$T_c = 212$ K	

Isotope effect



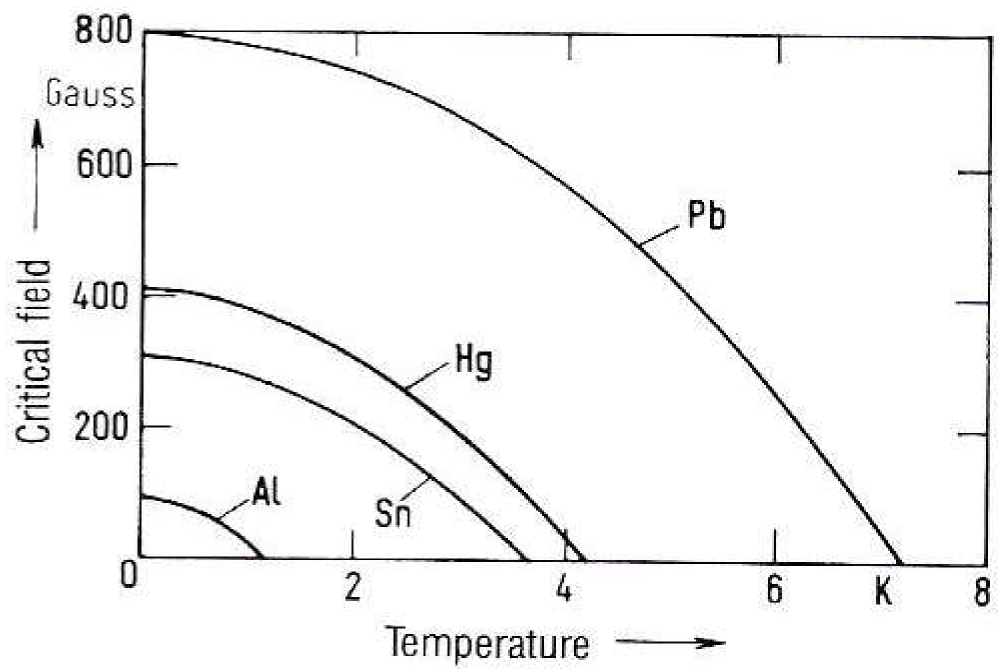
$$T_c \propto \frac{1}{\sqrt{m}}$$

Superconductivity

Critical temperature T_c

Critical current density J_c

Critical field H_c



$$n\Delta \approx nk_B T_c \approx \mu_0 H_c^2 \approx \tfrac{1}{2} nmv^2 = \frac{m}{2ne^2} J_c^2$$

Superconductivity

Perfect diamagnetism

Jump in the specific heat like a 2nd order phase transition, not a structural transition

Superconductors are good electrical conductors but poor thermal conductors, electrons no longer conduct heat

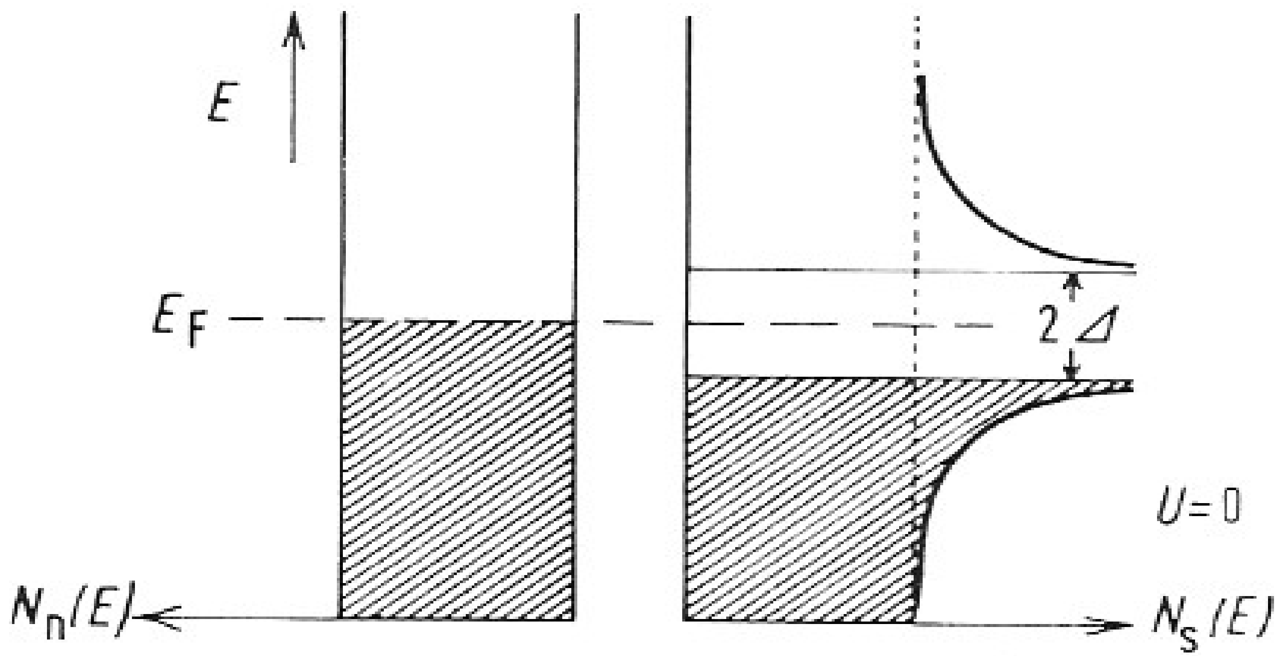
There is a dramatic decrease of acoustic attenuation at the phase transition, no electron-phonon scattering

Dissipationless currents - quantum effect

Electrons condense into a single quantum state - low entropy.

Electron decrease their energy by Δ but loose their entropy.

Density of states



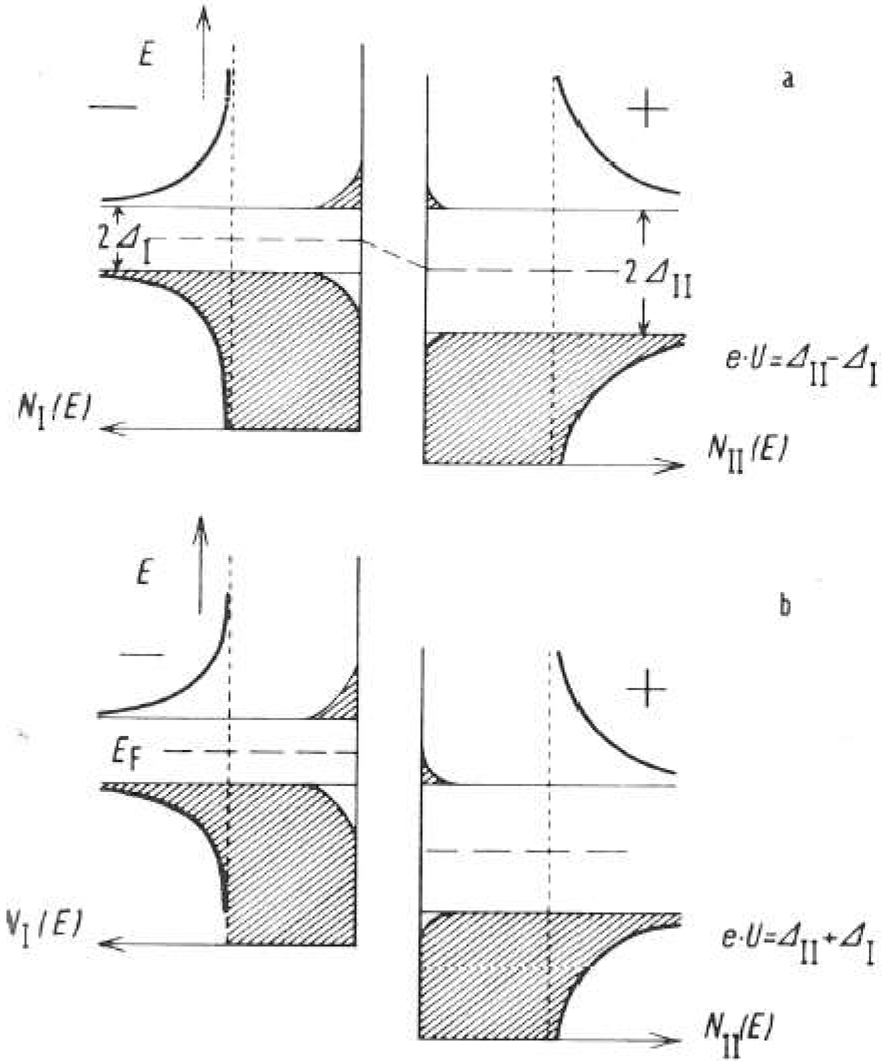
Condensate at E_F

Build wave packets out of states near E_F - Cooper pairs

exchange electrons $\Psi \rightarrow -\Psi$ exchange CP $\Psi \rightarrow \Psi$

no states within Δ of E_F

Tunneling spectroscopy



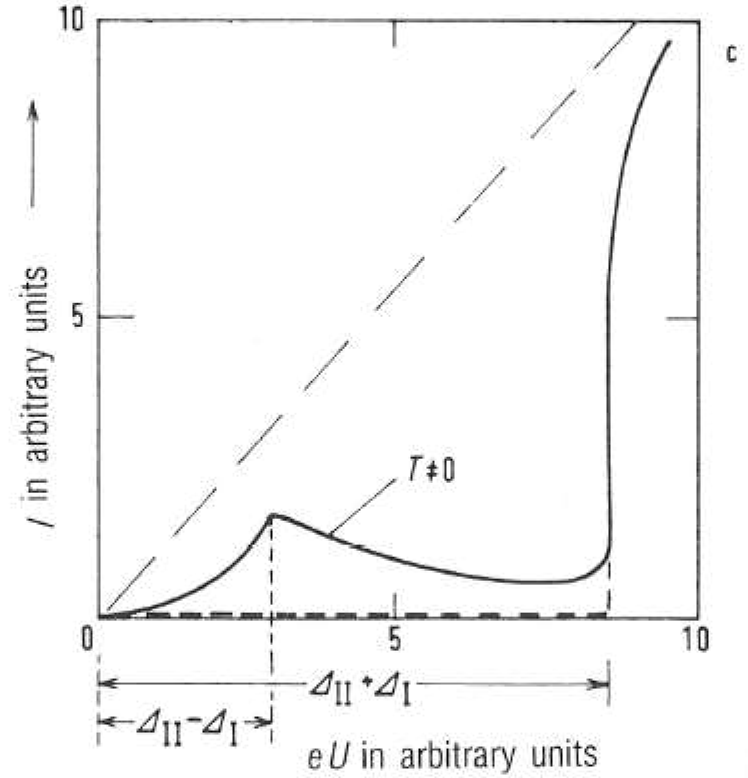


Fig. 31. Tunneling current between two superconductors $0 < T < T_c$.

Buckel - Superconductivity

BCS theory (1957)

Electrons form Cooper pairs

Electrons condense into a coherent state. Similar to:

- Superfluidity
- Bose-Einstein condensates
- Lasers

Pauli exclusion: the sign of the wavefunction changes when two electrons are exchanged.

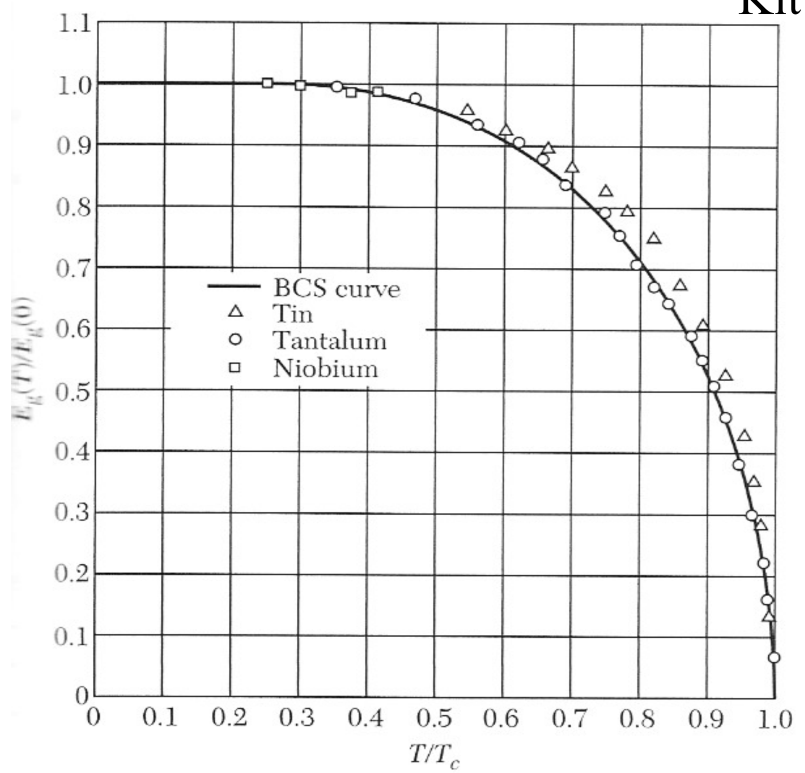
1972

BCS results

$$\frac{\Delta(0)}{k_B T} = 1.76$$

Al	1.7
Cd	1.6
In	1.8
Hg	2.3
Nb	1.9
Pb	2.1
Sn	1.7

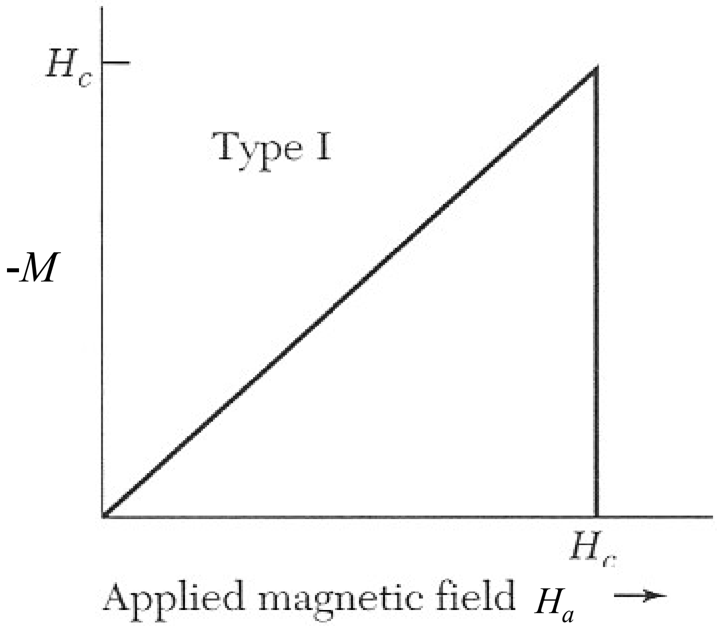
Kittel

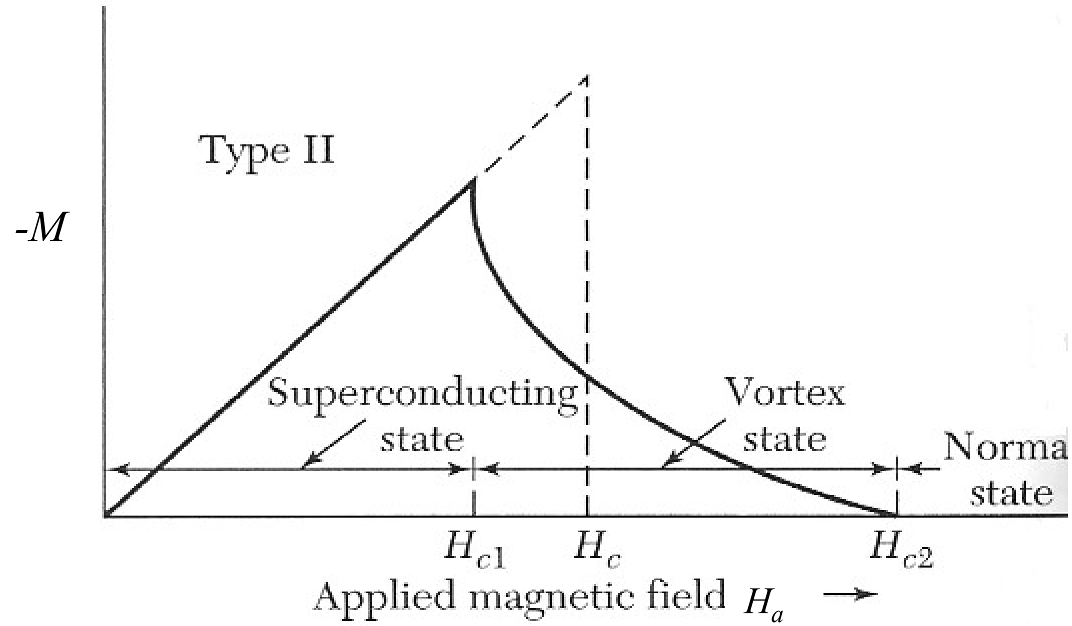


$$\left.\frac{c_s - c_n}{c_n}\right|_{T=T_c} = 1.43$$

Al	1.4
Cd	1.4
In	1.7
Hg	2.4
Nb	1.9
Pb	2.7
Sn	1.6

Type I and Type II





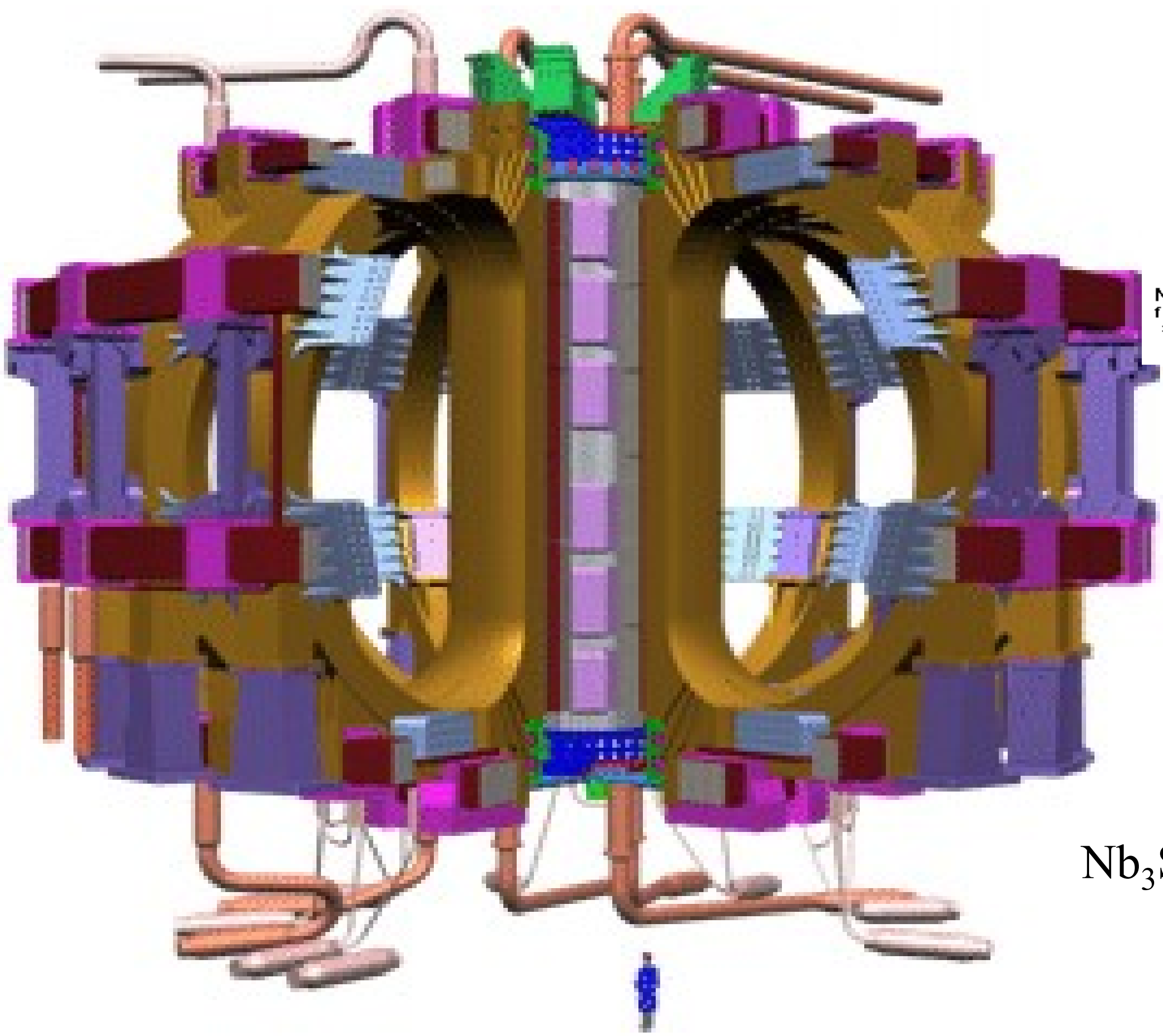
$$\vec{B} = \mu_0 \left(\vec{H} + \vec{M} \right)$$

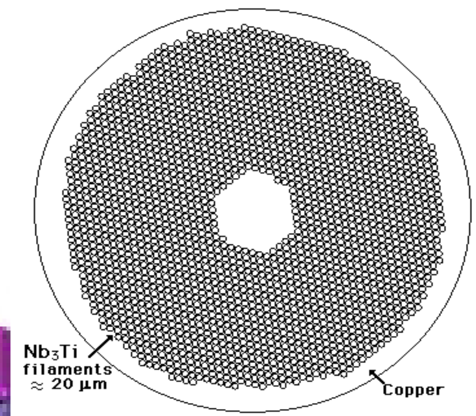
Superconductors are perfect diamagnets at low fields.
B=0 inside a bulk superconductor.

Superconducting Magnets

Whole body MRI

ITER

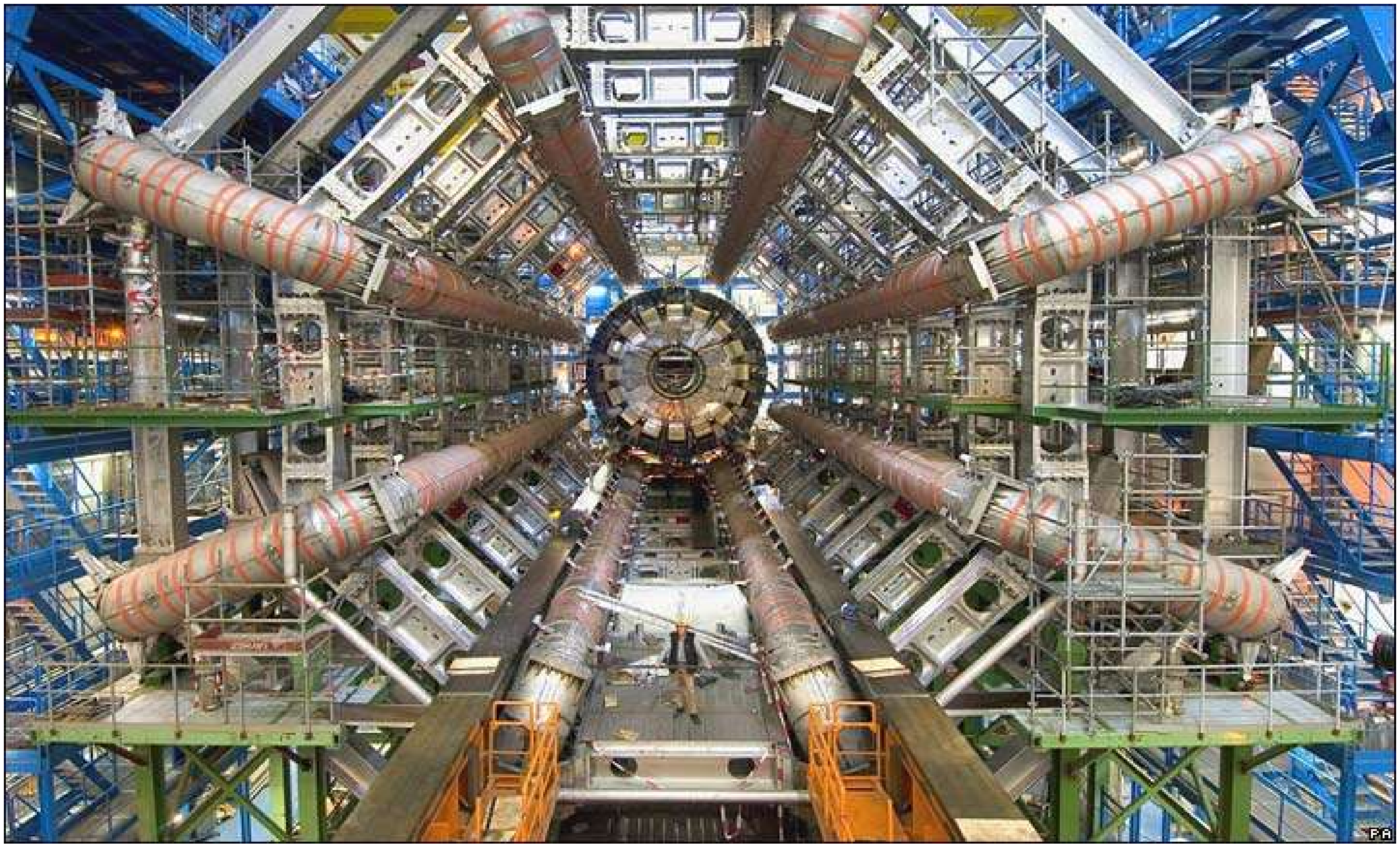




Magnet wire

Nb_3Sn Magnet

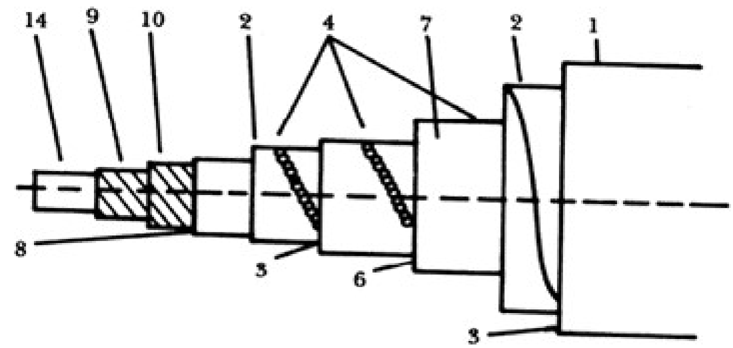
Superconducting magnets



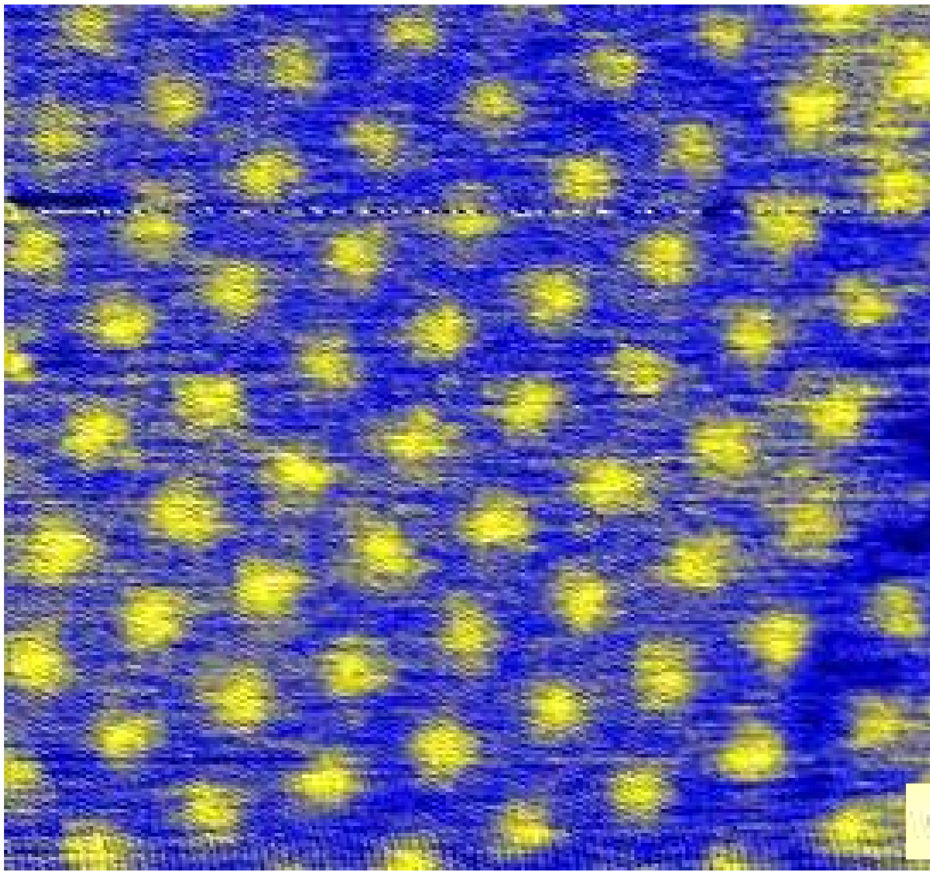
Largest superconducting magnet, CERN
21000 Amps

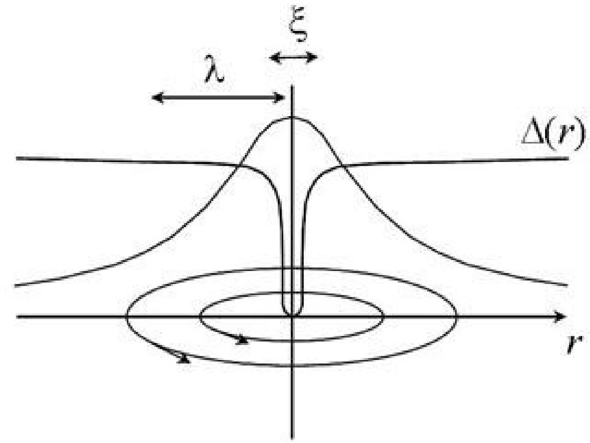
Magnets and cables

Maglev trains



Vortices in Superconductors





$$\Phi_0 = h/2e \simeq 2 \times 10^{-15} \text{ Tesla m}^2$$

STS image of the vortex lattice in $NbSe_2$.
(630 nm x 500 nm, B = .4 Tesla, T = 4 K)

http://www.insp.upmc.fr/axe1/Dispositifs%20quantiques/AxeI2_more/VORTICES/vortexHD.htm