The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2234-17

Meeting of Modern Science and School Physics: College for School Teachers of Physics in ICTP

27 April - 3 May, 2011

The century jubilee of superconductivity

Ruggero Vaglio

SPIN-CNR and University of Naples
Italy

Istituto SPIN-CNR

Trieste, April 28th 2011

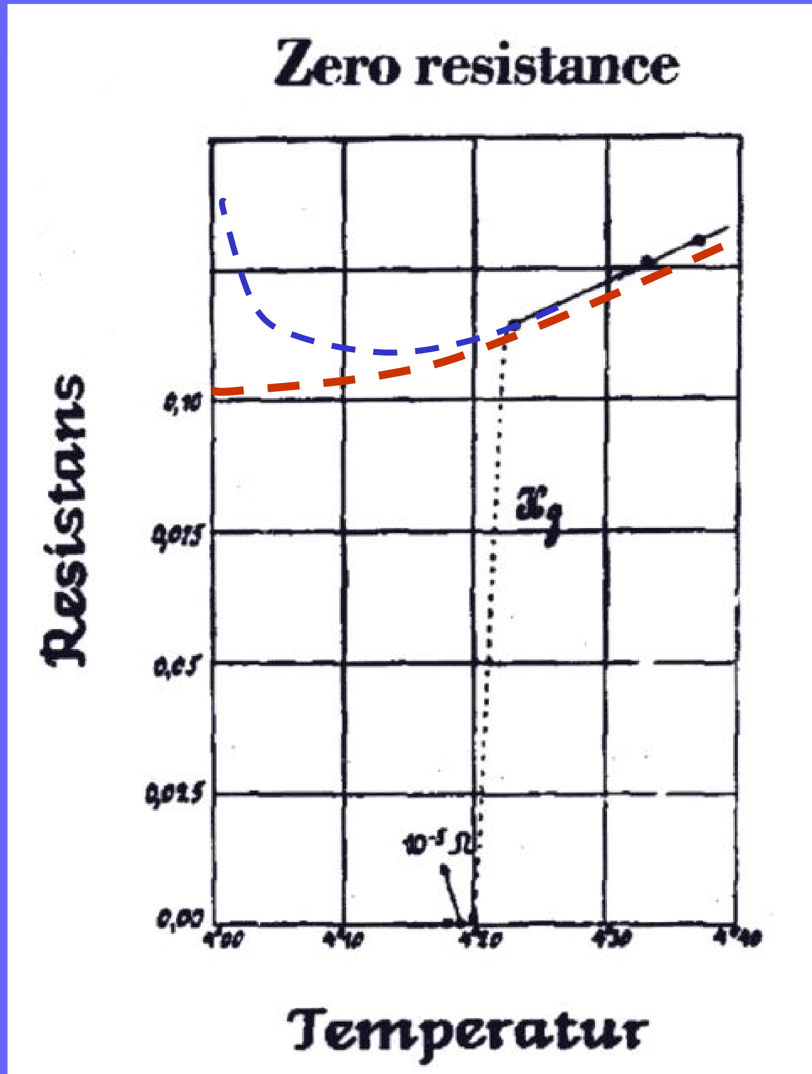
Universita' di Napoli Federico II

Ruggero Vaglio

The Century Jubilee of

Superconductivity

1911:The discovery of superconductivity



In 1911 Kamerlingh Onnes during his experiments on Helium liquefaction observed the sudden disappearance of mercury electrical resistance.

- In 1912 he discovered that electrical resistance reappeared in presence of intense magnetic fields or currents

Maximum current : J_c Maximum field : B_c

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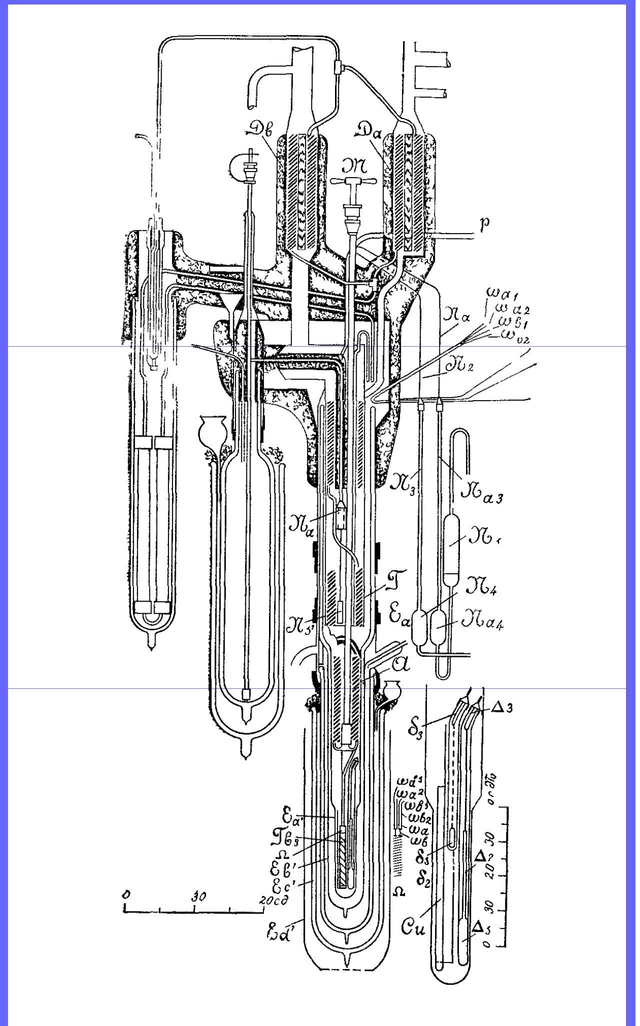
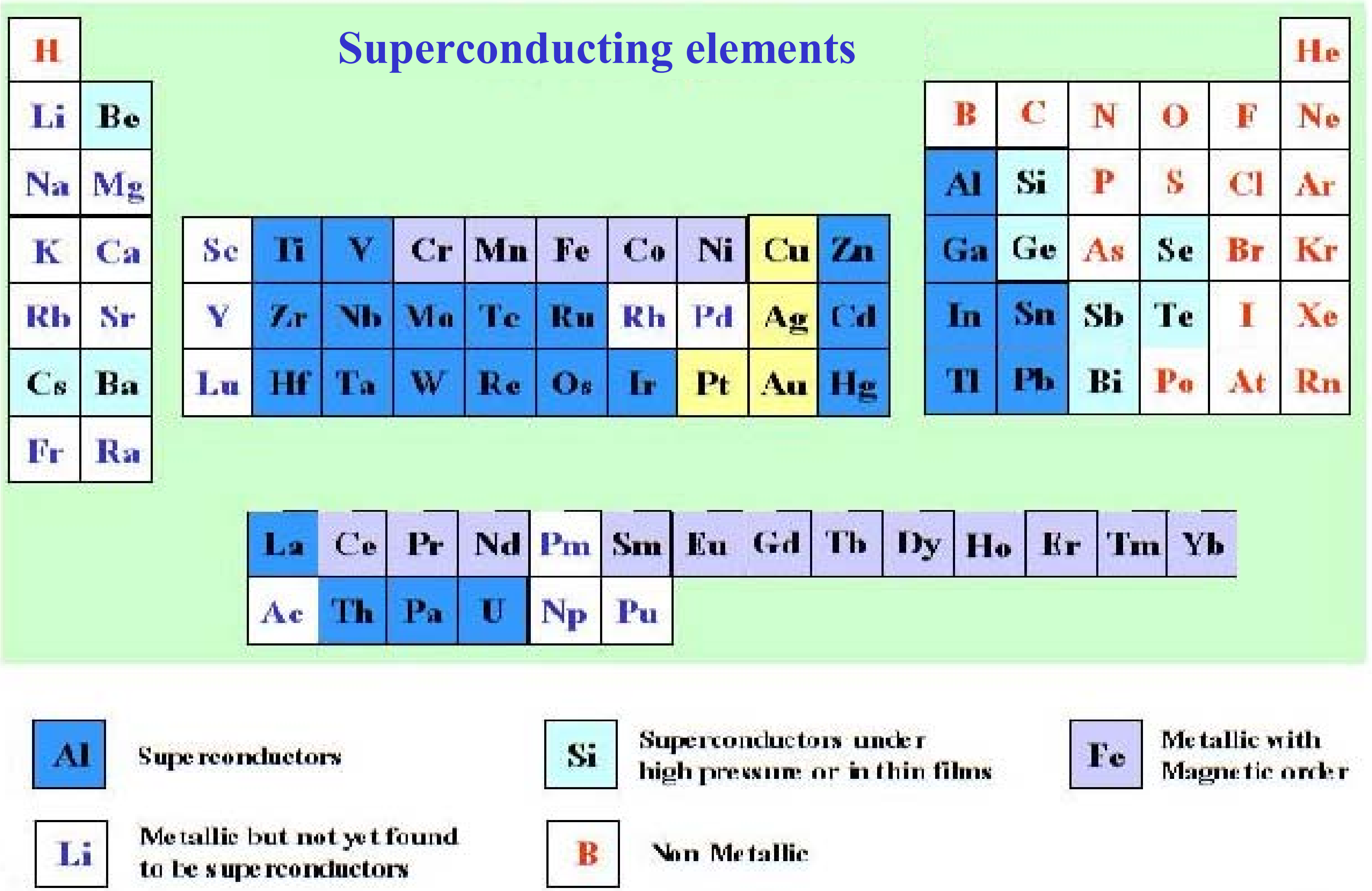
Kamerlingh Onnes Laboratory



1913

Superconducting elements



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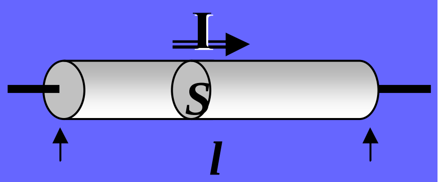
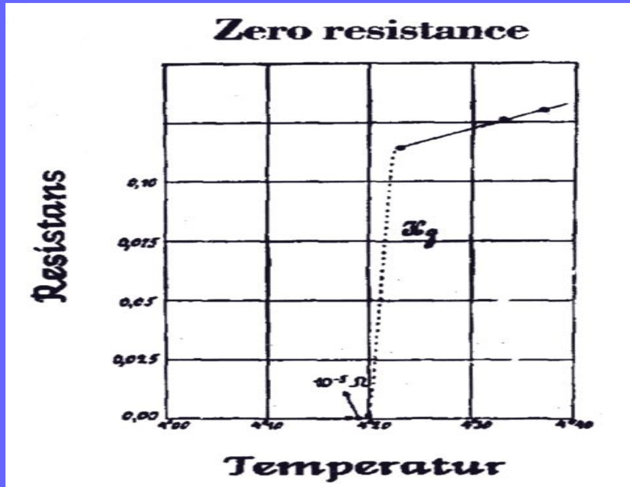
Zero Resistance



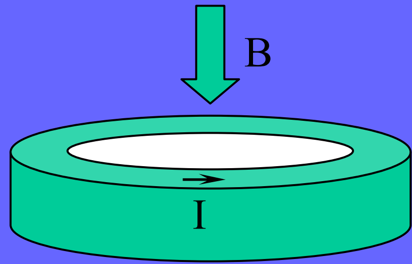
$$V = RI$$

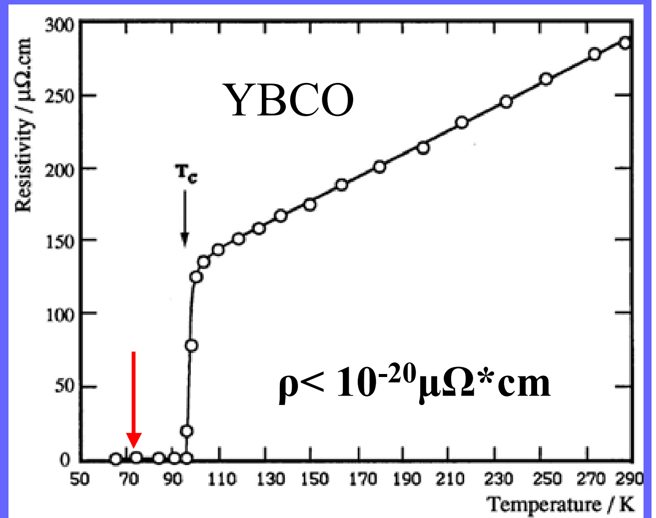
$$R = \rho \frac{l}{S}$$



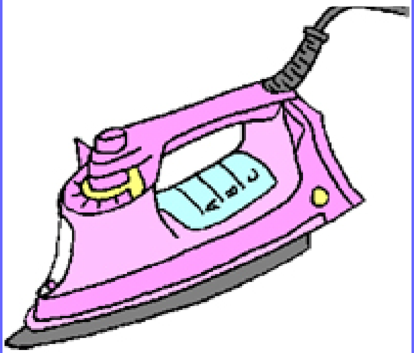
$$I = I_0 e^{-\frac{t}{\tau}}$$

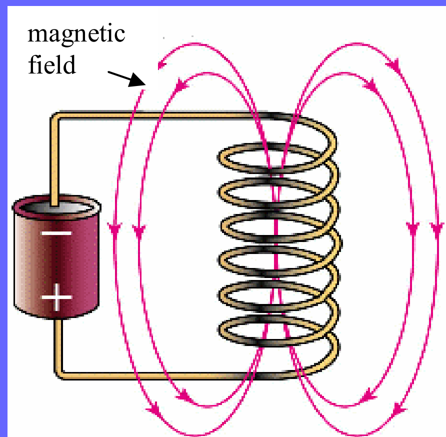
$$\tau = \frac{L}{R}$$



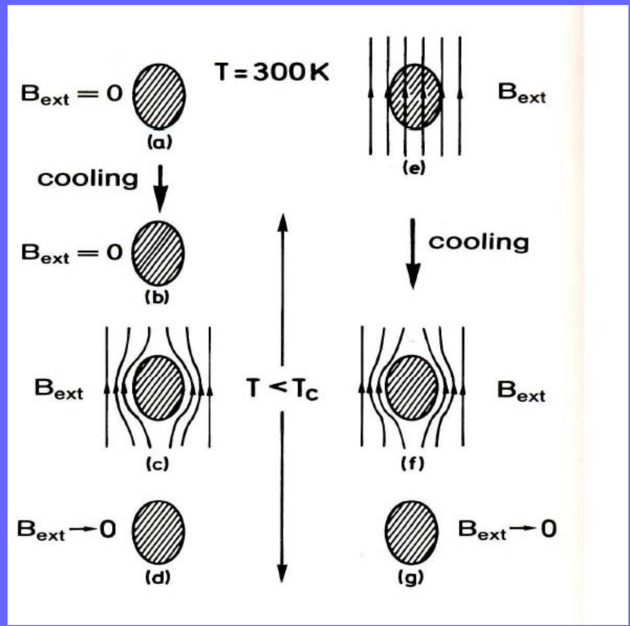


$$P = RI^2$$

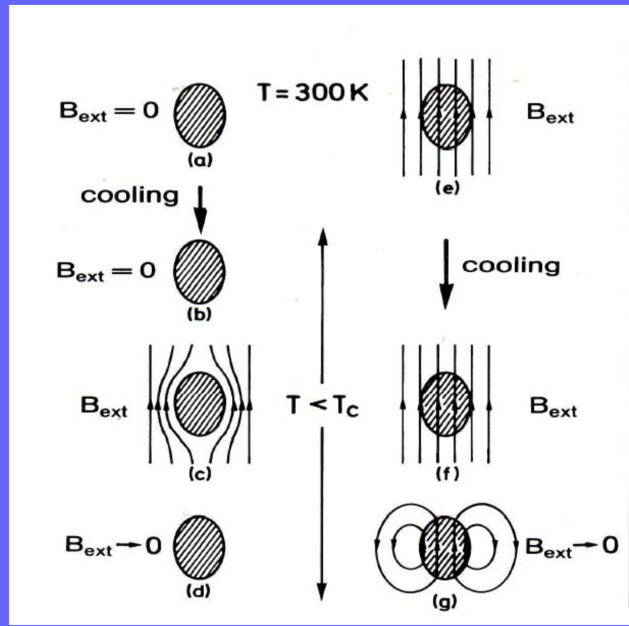




1933: The Meissner effect



superconductor



perfect conductor

- In 1933 Meissner discovered that superconducting elements expel the magnetic field, behaving as “perfect diamagnets”

A magnet can “levitate” over a superconductor (and viceversa)

The London 2-fluid Theory (1935)

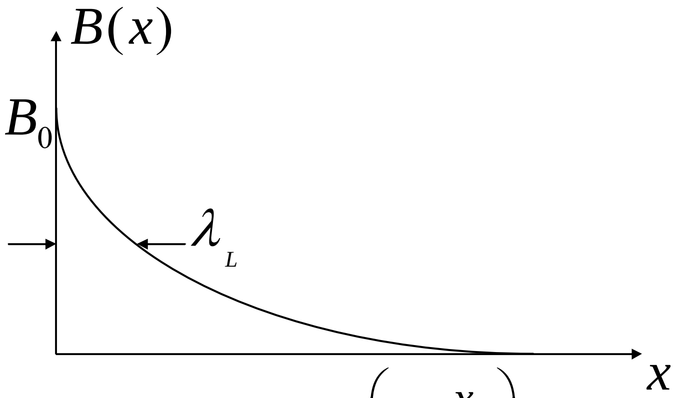
$$\begin{cases} \vec{J}_n = -n_n e \vec{v}_n \\ \vec{J}_s = n_s q_s \vec{v}_s \end{cases} \qquad \vec{v}_n = -\mu_n \vec{E} \qquad m_s \frac{d\vec{v}_s}{dt} = q_s \vec{E} \qquad \vec{J}_n = n_n e \mu_n \vec{E} \qquad \frac{d\vec{J}_s}{dt} = \frac{n_s q_s^2}{m_s} \vec{E}$$

$$+ \text{ Eq. Maxwell} \begin{cases} rot\,\vec{B} = \mu_o \vec{J}_s \\ rot\,\vec{E} = -\dfrac{\partial \vec{B}}{\partial t} \end{cases}$$

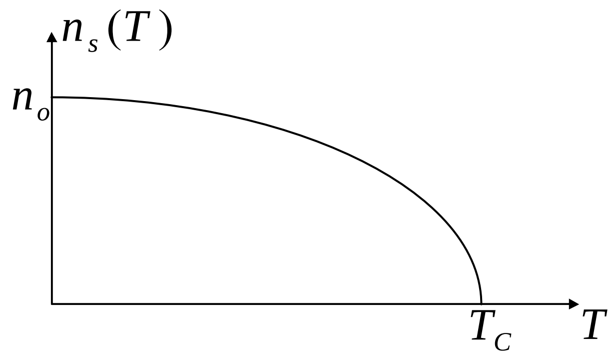
$$\begin{cases} rotrot\ \vec{B} = -\nabla^2 \vec{B} = \mu_o rot\,\vec{J}_s \\ \dfrac{\partial \mu_o rot\,\vec{J}_s}{\partial t} = \dfrac{\mu_o n_s q_s^2}{m_s} rot\,\vec{E} = -\dfrac{\mu_o n_s q_s^2}{m_s} \dfrac{\partial \vec{B}}{\partial t} \end{cases}$$

$$\frac{\partial}{\partial t}\left(\nabla^2 \vec{B} - \frac{1}{\lambda_L^2} \vec{B} \right) = 0$$

$$\lambda_L = \left(\frac{n_s q_s^2 \mu_0}{m_s} \right)^{-1/2}$$

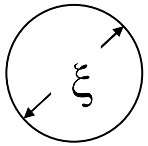


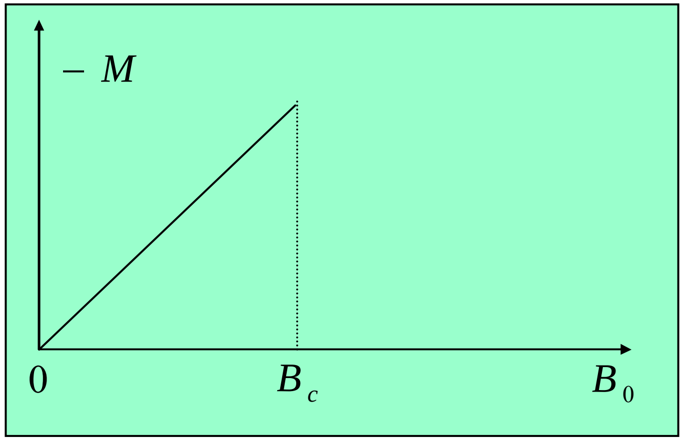
$$B(x) = B_o \exp\left(-\frac{x}{\lambda_L} \right)$$



Pippard (1950) ; Gizburg - Landau (1950)

Deviation of values of the penetration depth magnetic from London predictions and anomalous Meissner effect for alloys :

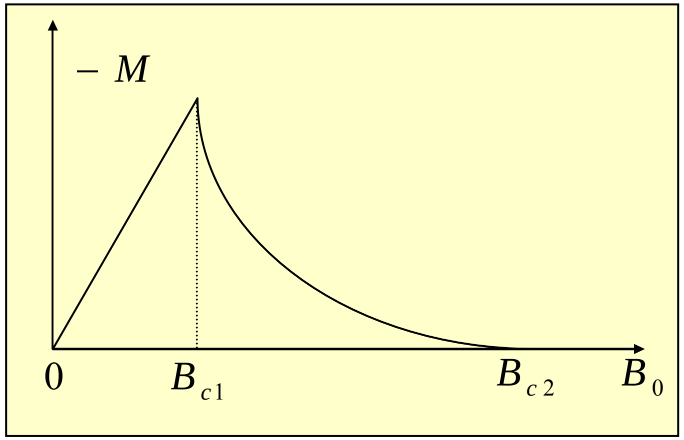




Type I superconductors

(Pb, Sn, In, Al)

$$k \equiv \frac{\lambda}{\xi} < \frac{1}{\sqrt{2}}$$



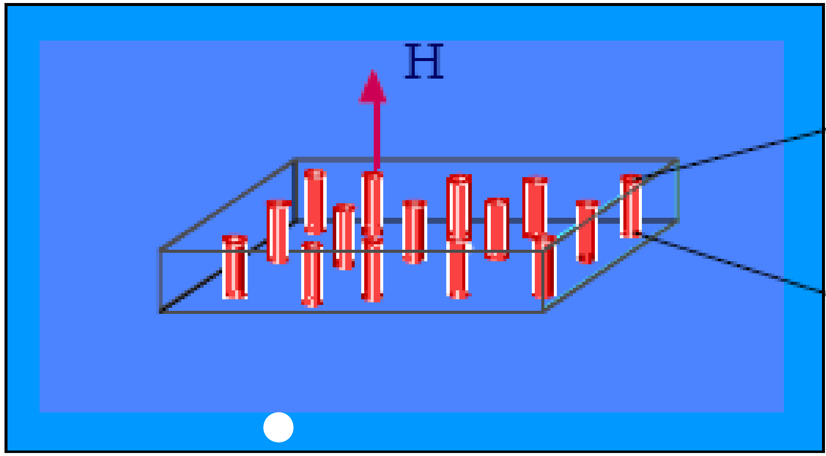
Type II superconductors

$(Nb, alloys)$

$$k \equiv \frac{\lambda}{\xi} > \frac{1}{\sqrt{2}}$$

Explanation of type II Superconductivity : Abrikosov Vortices

Type II superconducting sample in a magnetic field



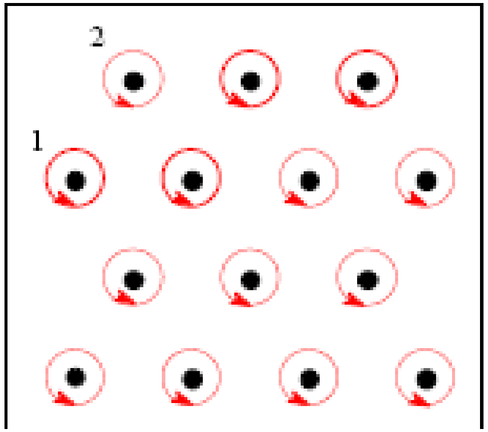
normal zones

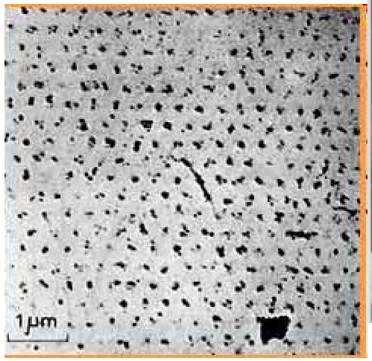
2003

me

$$B_{c2}\xi^2 = \phi_0$$

exagonal vortex lattice





Critical currents are limited by vortex mobility (pinning)

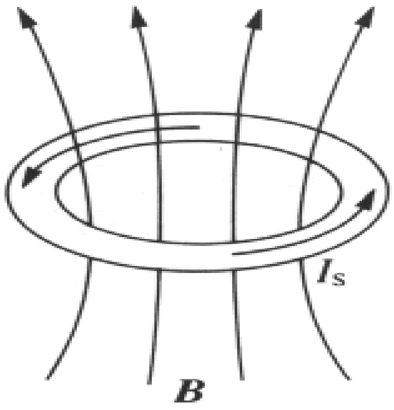
GL theory :quantum interpretation

$n_s(T) = |\psi|^2$ (Ψ is interpreted as a macroscipic quantum wave-function)

$$\psi = \psi_0 e^{i\varphi} = n_s^{1/2} e^{i\varphi}$$

$$\vec{J}_s = n_s q_s \vec{v}_s = \frac{n_s q_s}{m_s}\left(\hbar \vec{\nabla}\varphi - q_s \vec{A}\right)$$

Flux Quantization



$$\vec{J}_s = 0 \Rightarrow \hbar \vec{\nabla}\varphi = q_s \vec{A}$$

$$\hbar \oint \vec{\nabla}\varphi \cdot d\vec{l} = q_s \oint \vec{A} \cdot d\vec{l} = q_s \int_S \vec{B} \cdot d\vec{S}$$

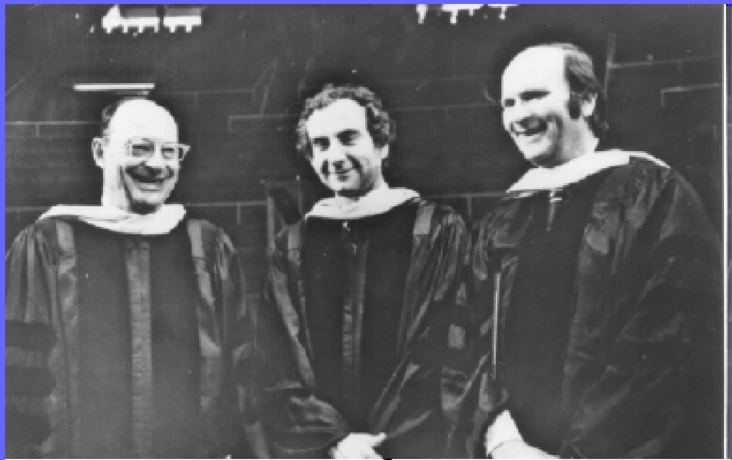
$$\hbar 2\pi n = q_s \phi$$

$$\phi = n\phi_0$$

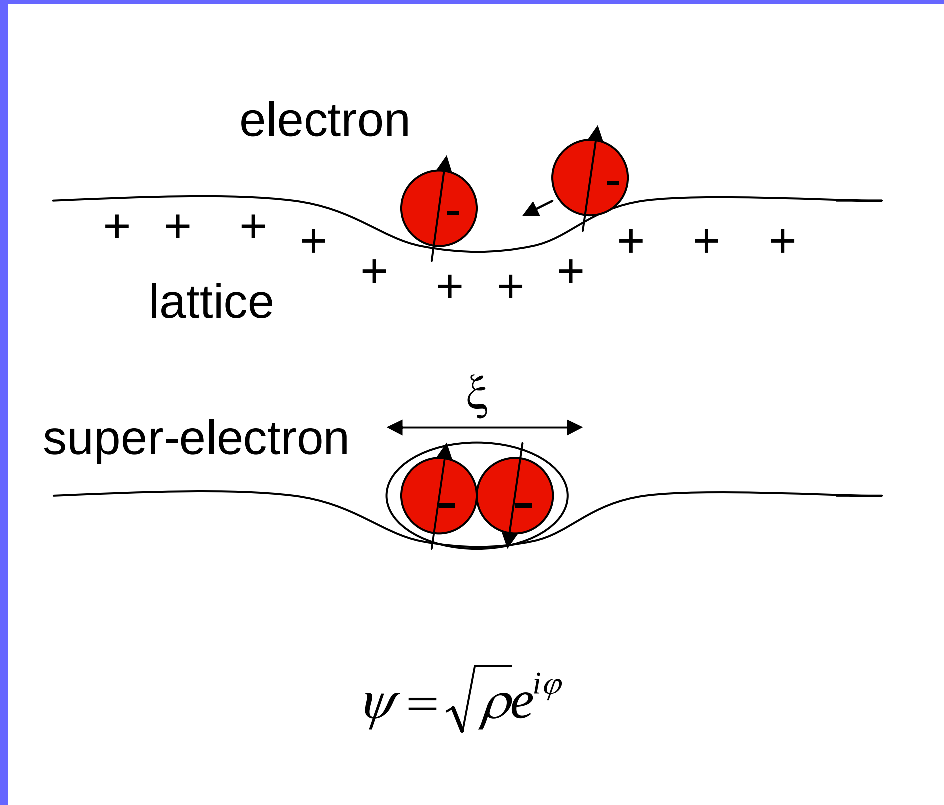
$$\phi_0 = \frac{h}{q_s} = 2 \cdot 10^{-7}\, gauss \cdot cm^2$$

From experimental observation $q_s = 2e$!

1957: The BCS theory

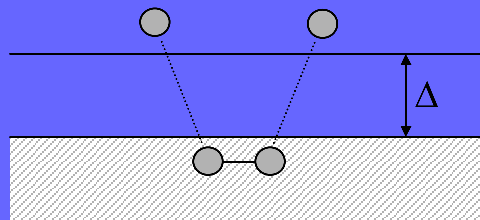


$$T_c = (2\hbar\omega_D\gamma/\pi)\exp[-2/(gv)].$$

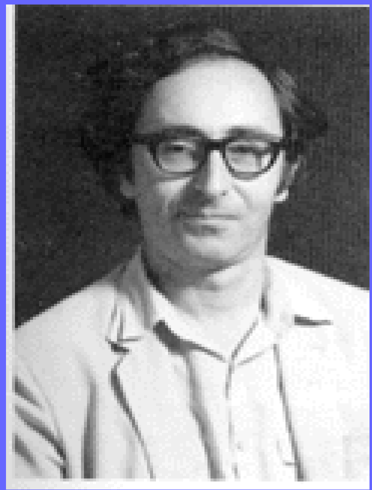


The BCS theory is based on the interaction of electrons with lattice vibrations (phonons) . Its extension (Eliashberg) give correct predictions of critical temperatures (and of the reasons why Cu and Fe are not superconductors) and of the“isotope effect”’

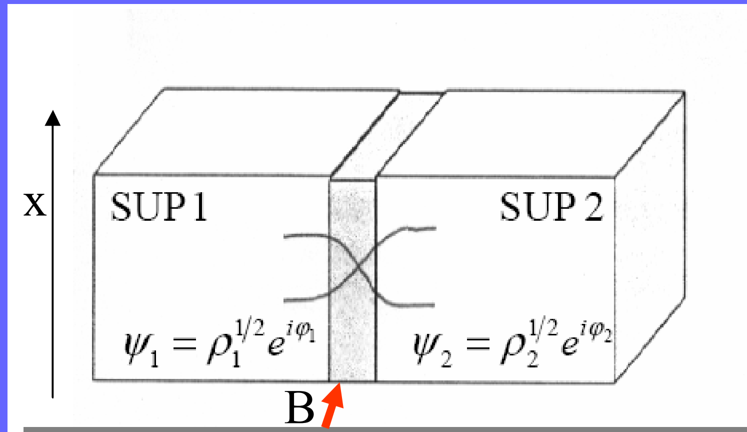
1972



1962: The Josephson effect



Josephson predicted that super-electrons could pass through an insulating barrier by tunnel effect



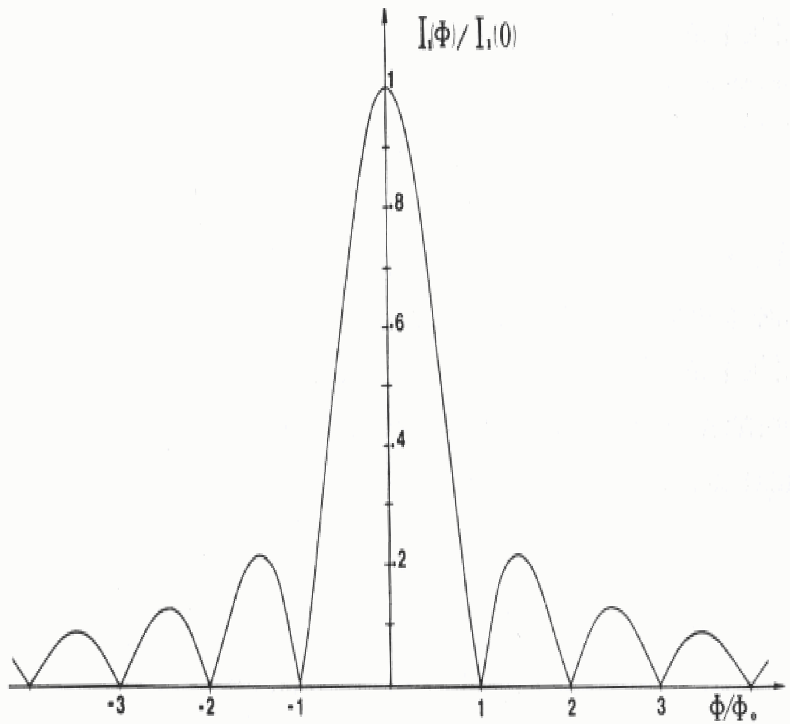
$$J = \frac{2K}{\hbar}\sqrt{\rho_1 \rho_2}\, \sin\varphi = J_1 \sin\varphi$$

$$\frac{\partial \varphi}{\partial t} = \frac{2e}{\hbar} V$$

$$\frac{\partial \varphi}{\partial x} = \frac{2ed}{\hbar c} B$$

1973

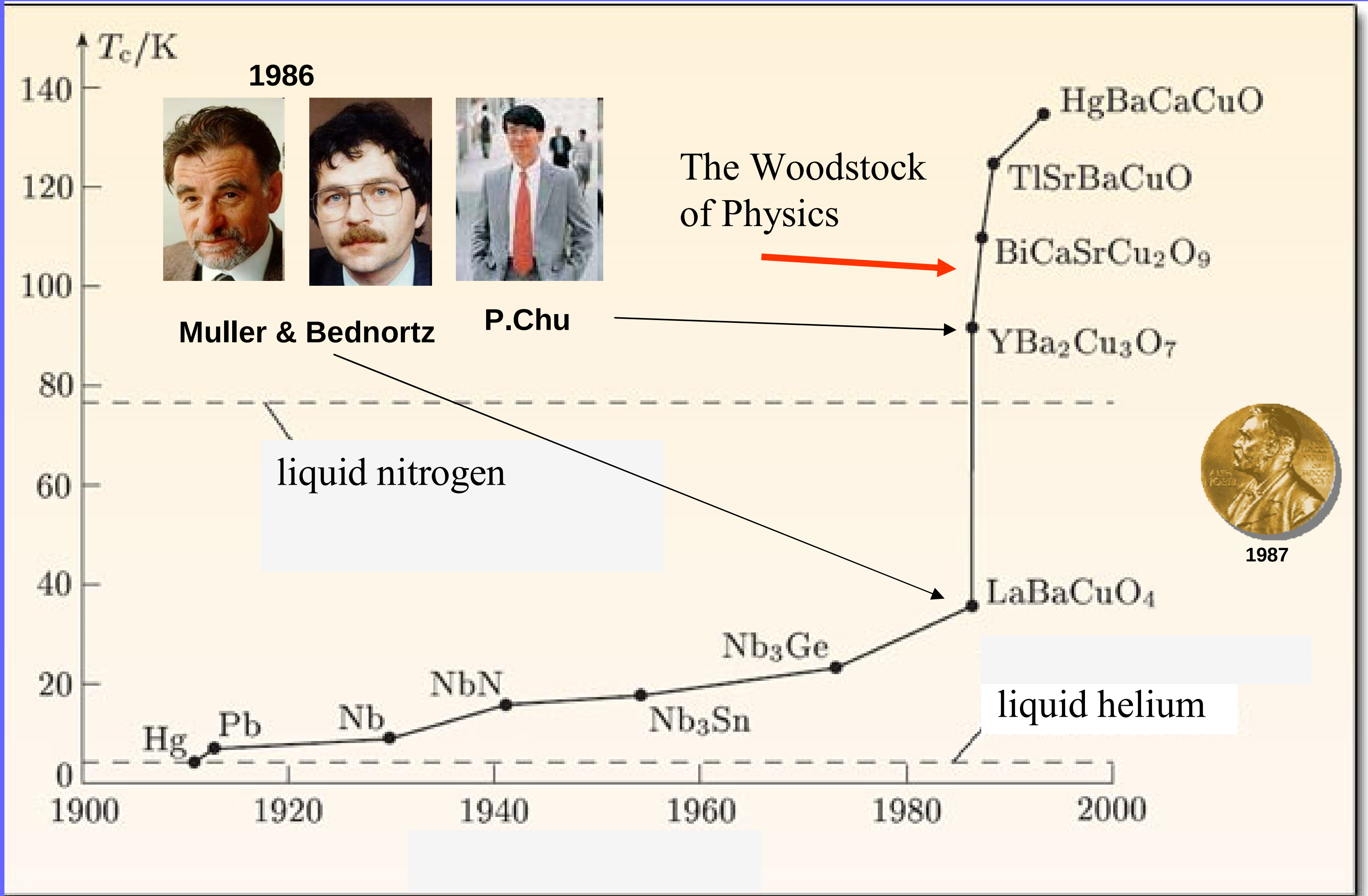
"Theory and Applications of the Josephson Effect"
Barone e Paterno' , Wiley 1982



Theoretical magnetic field dependence of the maximum Josephson current I_1 for a rectangular junction.

The magetic field sensitivity can reach 10^{-11}gauss

The high Tc race



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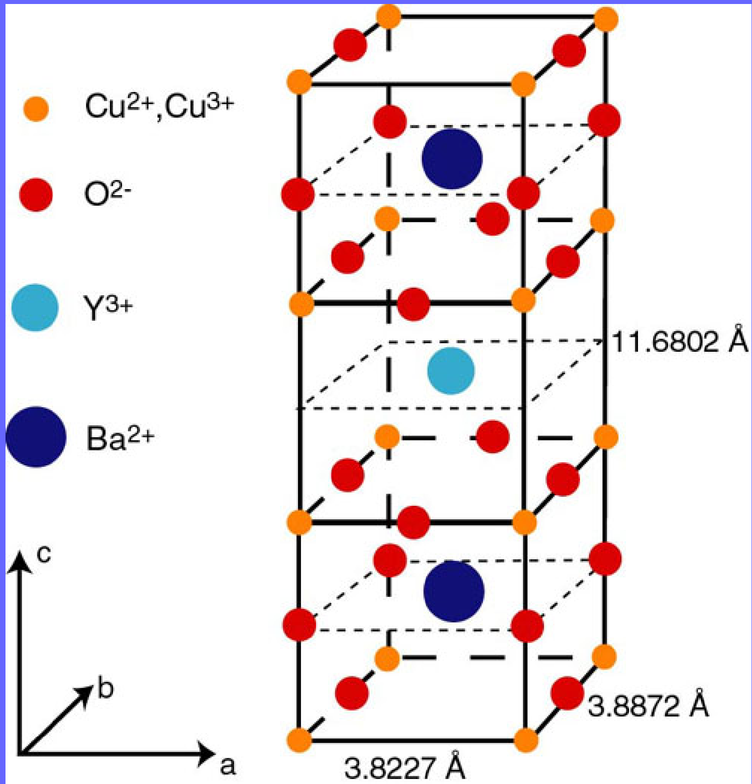
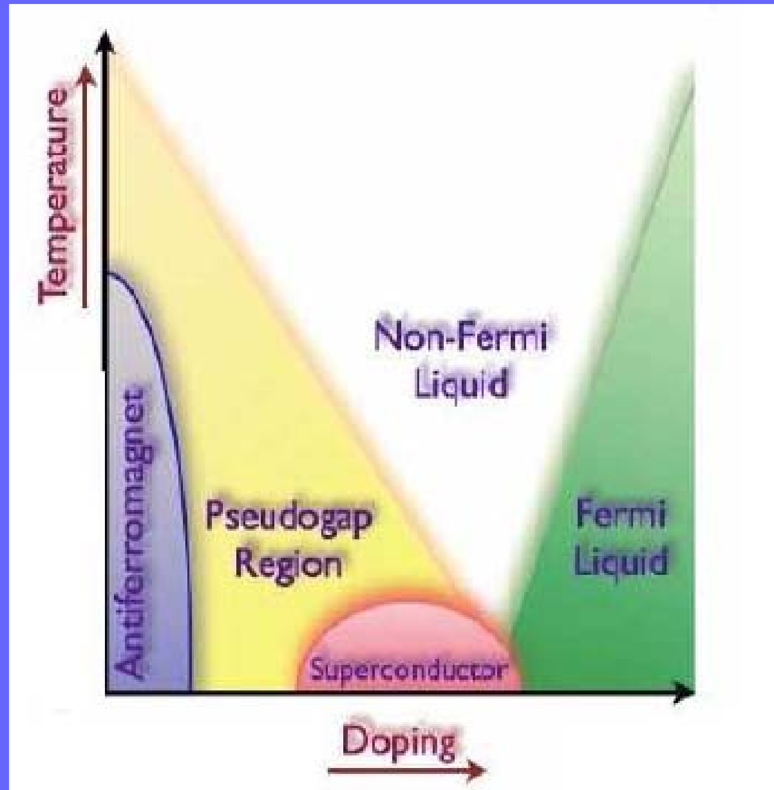
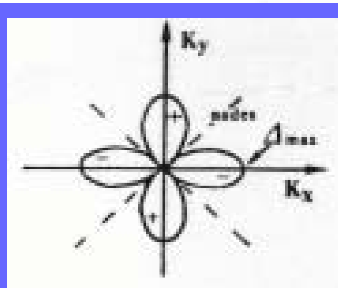
High Tc Superconductors





$YBa_2Cu_3O_{6+d}$

(type II, q_s=2e)



d-wave simmetry

($d_{x^2-y^2}$)

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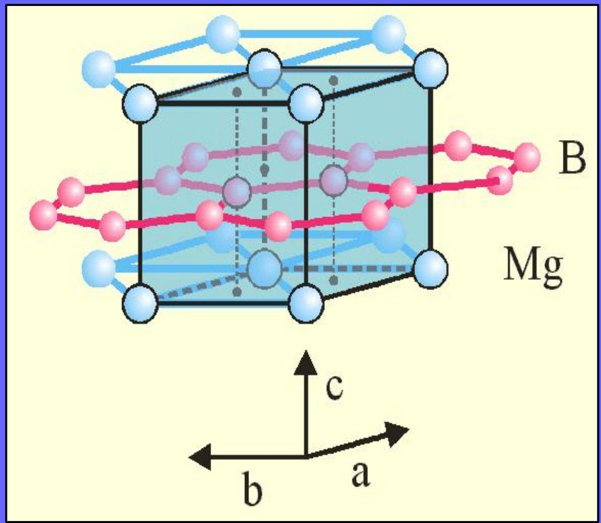
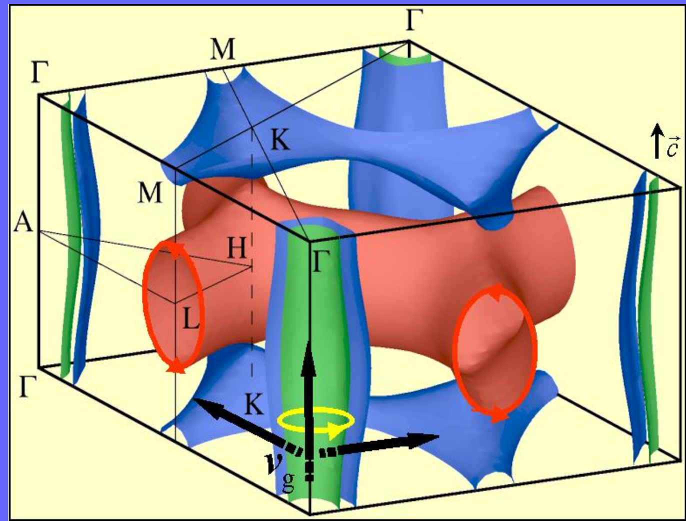
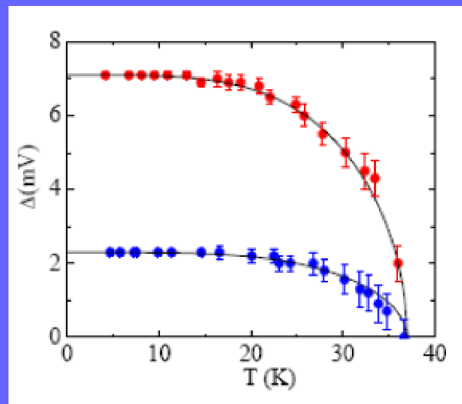
2001 : MgB_2 Tc= 40K :

the "best" conventional metallic superconductor !



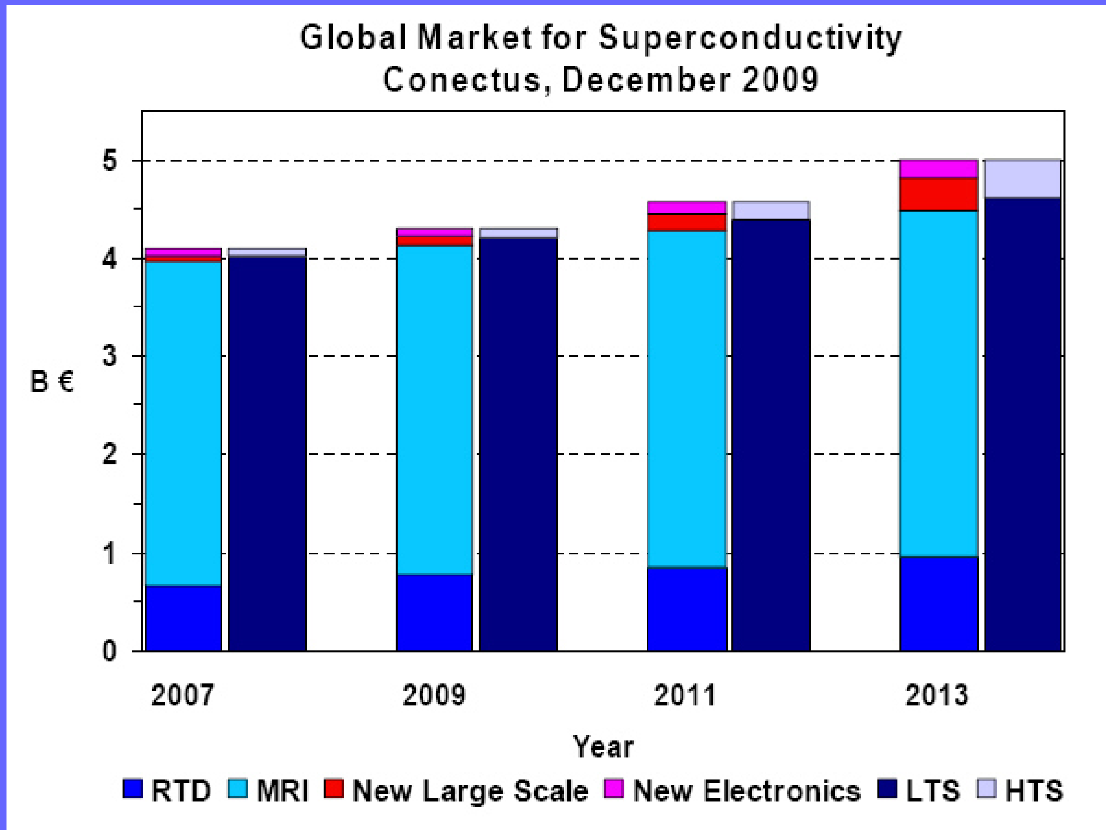


Two-band, two-gaps superconductor !

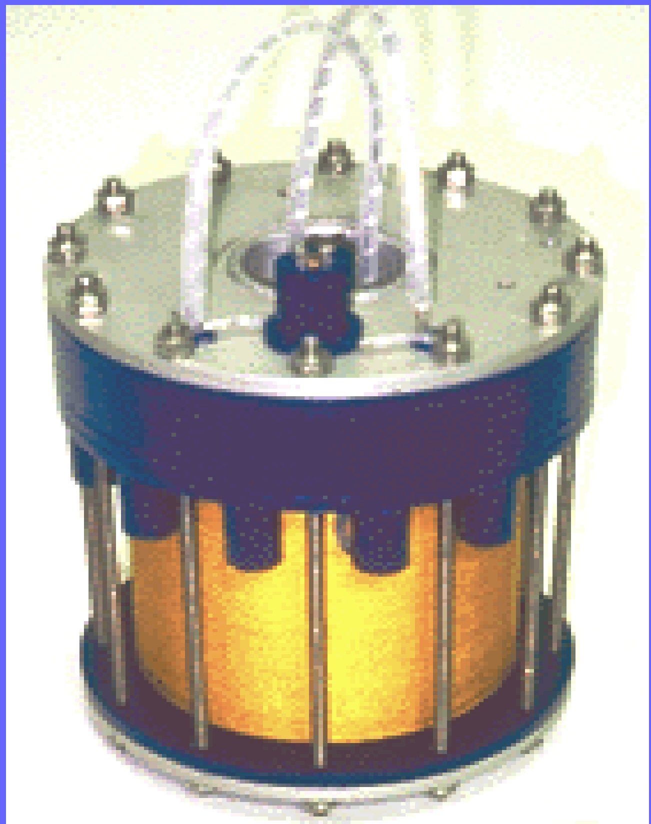


Applications

a) Zero Resistance (magnets and transport)
b) Josephson effect (magnetic field sensors and electronics)



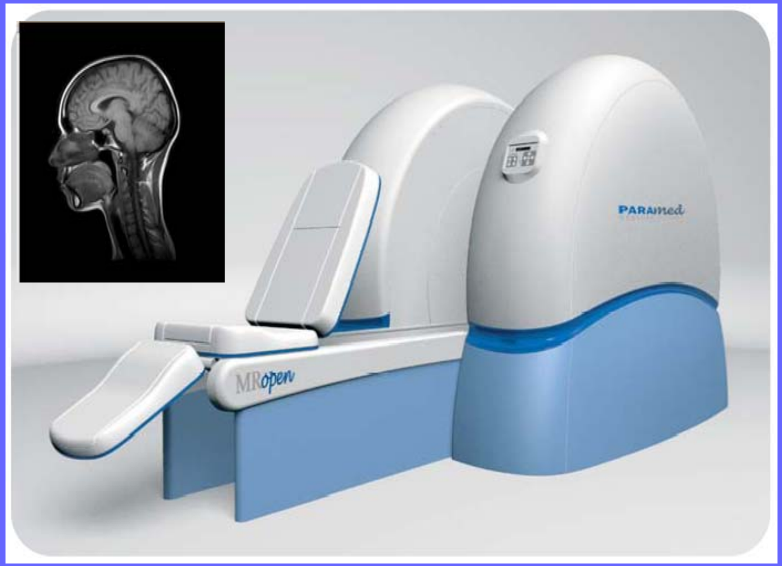
Superconducting magnets for research laboratories



NbTi

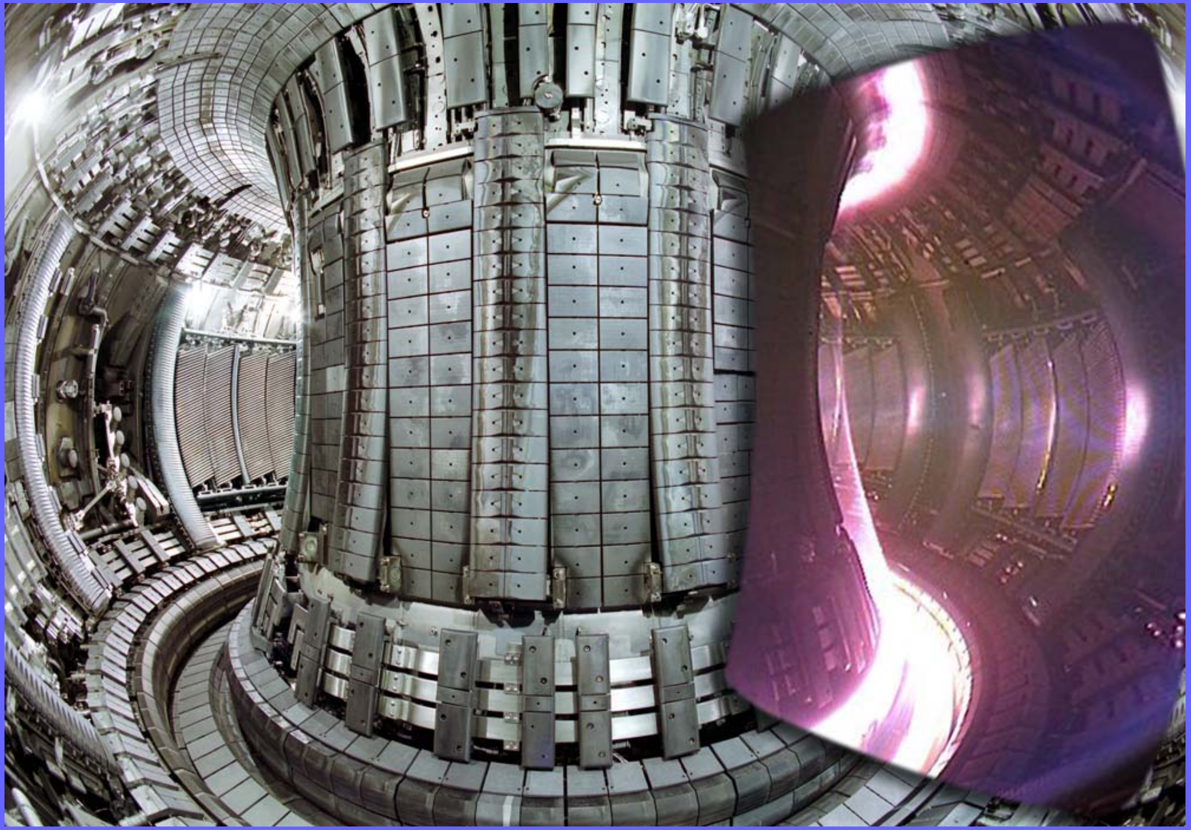
MgB_2

Magnets for MRI



Columbus Superconductors SPIN- Genova

Magnets for fusion experiments (ITER)



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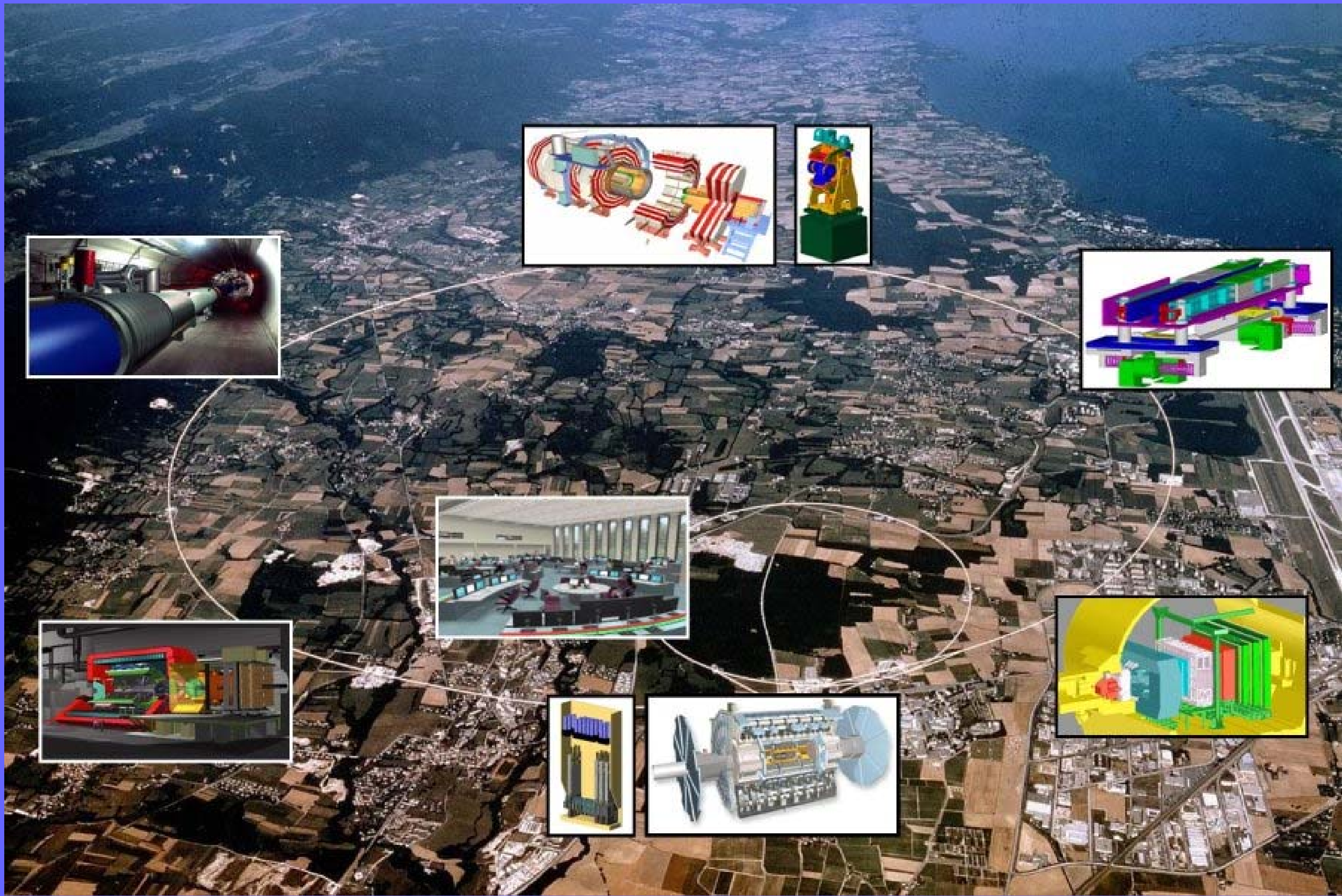
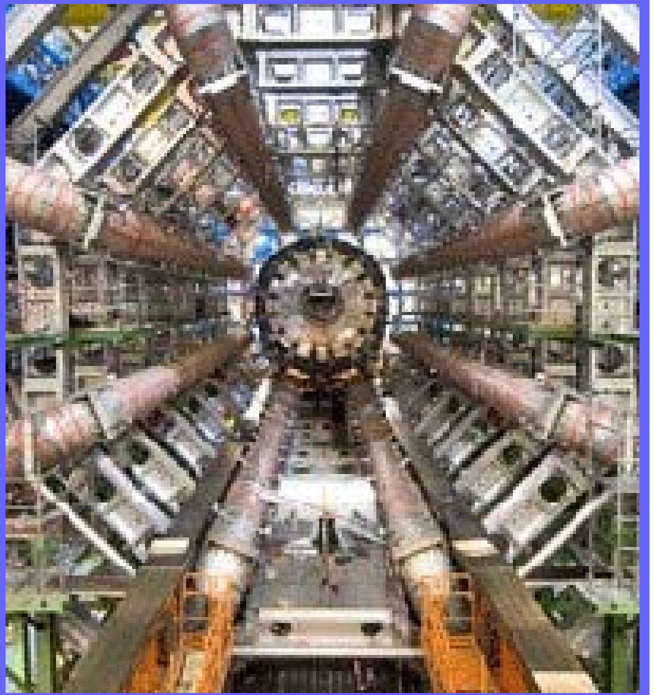
High Energy Physics



LHC Superconducting Magnets



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Superconduting Motors an Generators

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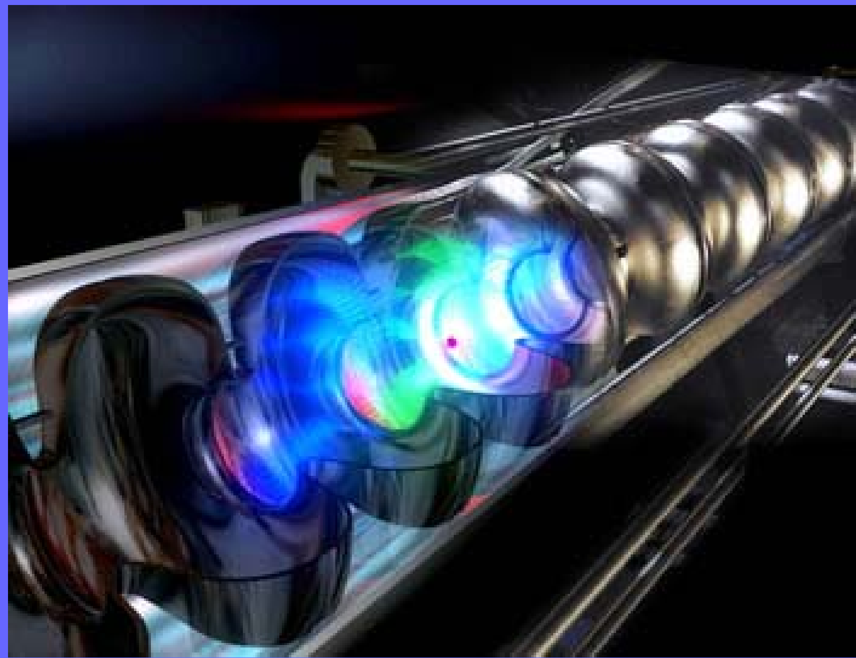
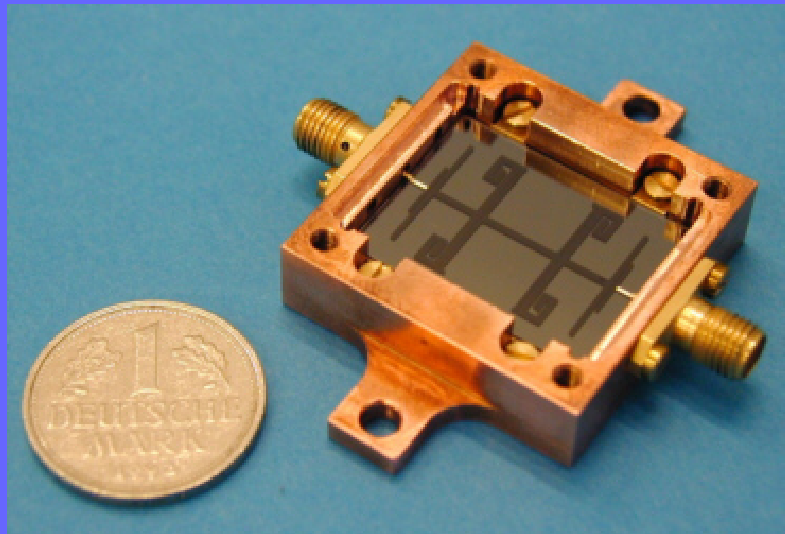
Superconducting Accelerating Cavities



Passive filters for cellular communications (BST)



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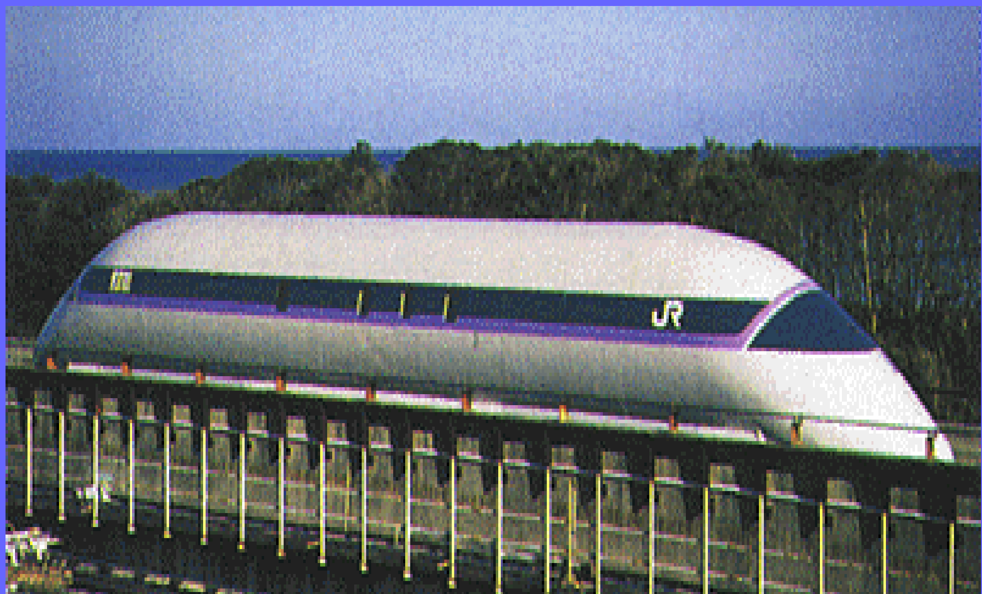
Magnetic Levitation MAGLEV Trains



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High Tc superconducting cables for high efficiency connections

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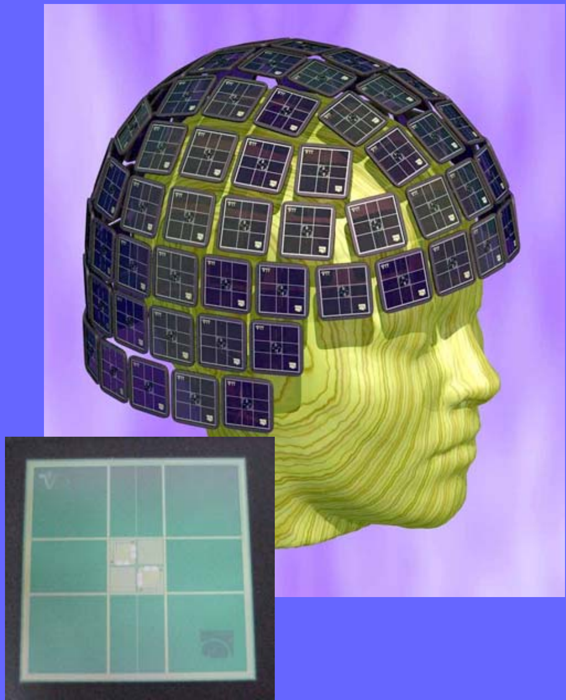
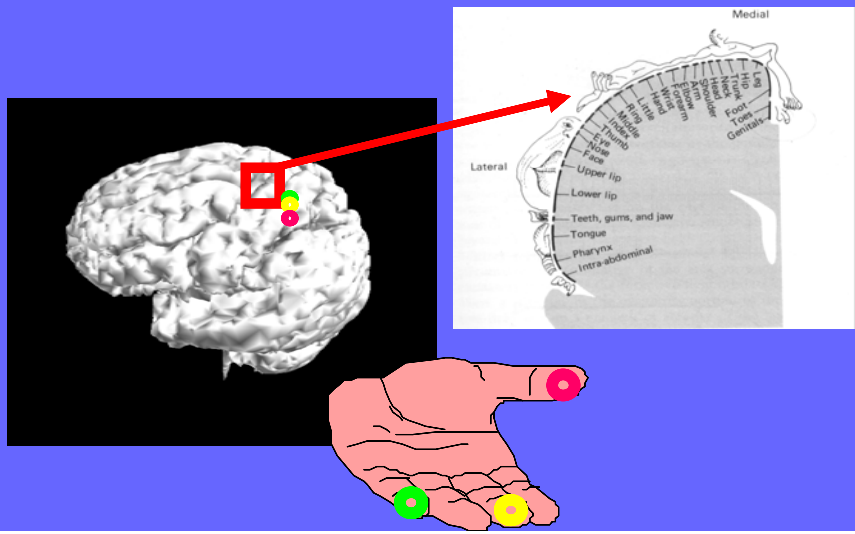
SQUID for Biomagnetism





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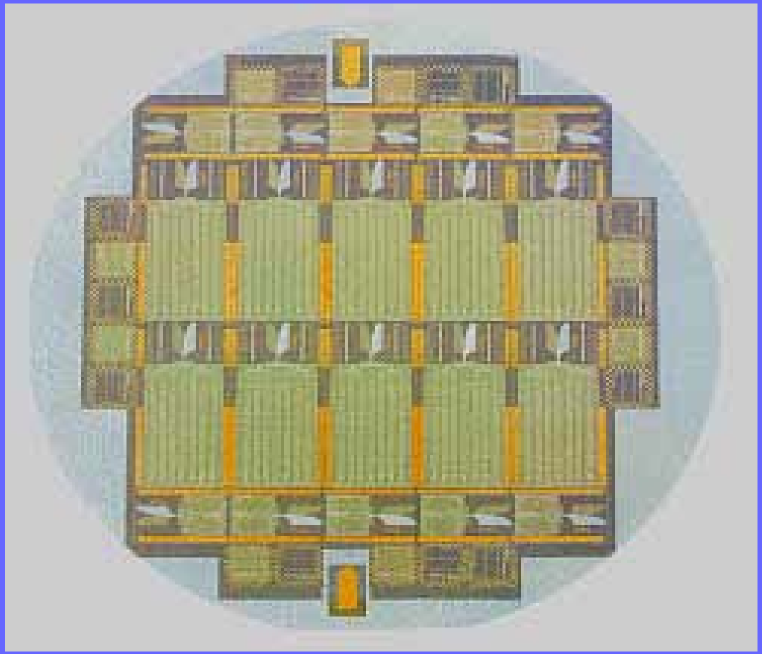
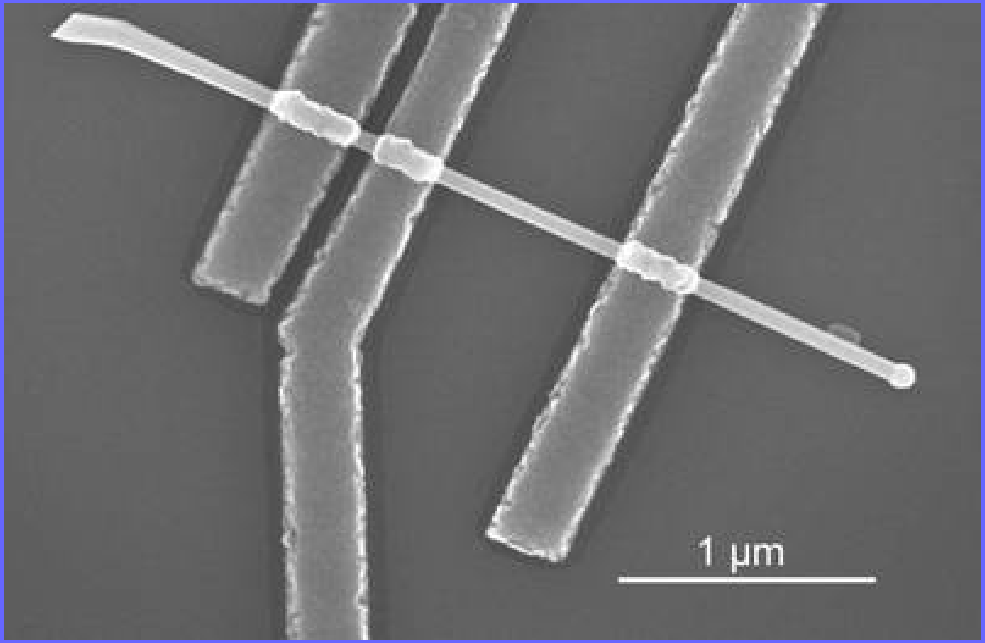
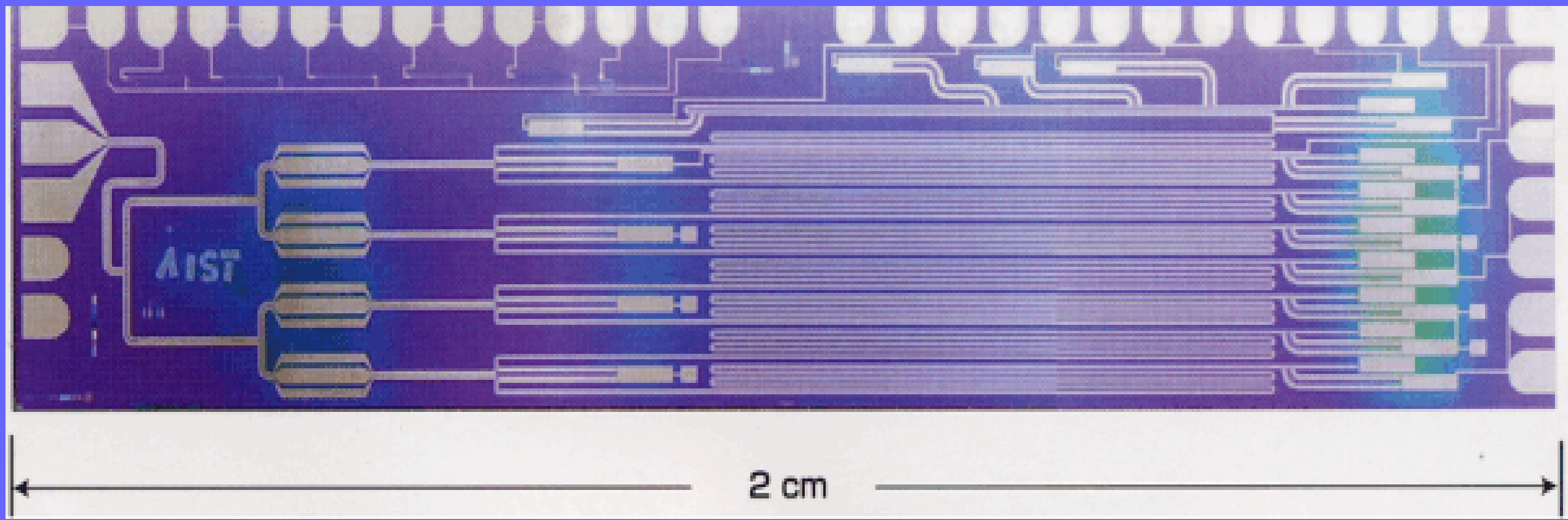
Josephson junctions and superconducting circuits for electronics and quantum computation





Voltage standard maintenance



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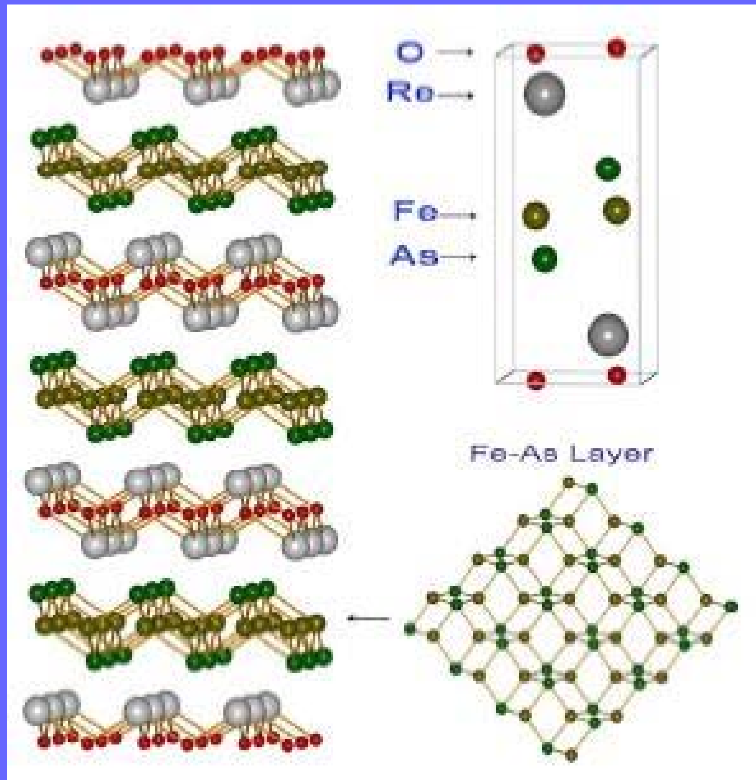
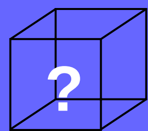
Search for Room Temperature Superconductors !



REOFeAs → 

AVATAR

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AVATAR

The need to conquire Pandora is because of room temperature superconductors rocks (based on "unobtanium" , an element with atomic number 120)

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The Superconductive City