Superconductivity Practical Days at CERN

1st and 2nd March 2018

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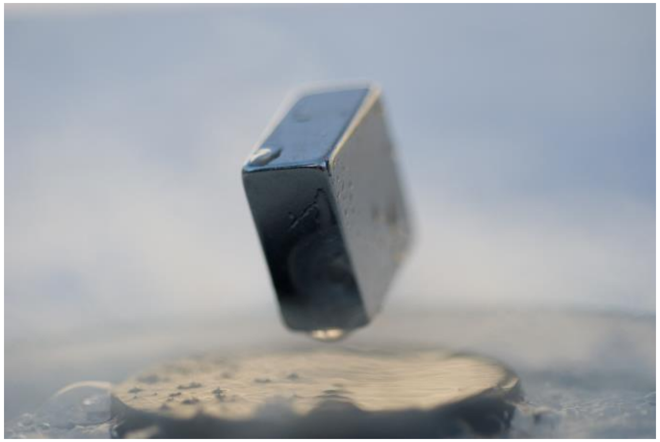
Introduction

- **Definition**
- **Main properties of Superconductors**
- **Superconductivity Applications**
- **Practical work**
- **Agenda of the days**

What will you do ?

Measure electrical, magnetic and thermal characteristics of superconducting samples with the purpose of understanding the fundamental characteristics of superconductors



Definitions

Superconductivity

"Superconductivity is a phenomenon occurring in certain materials at very low temperatures , characterized by exactly zero electrical resistance and the exclusion of the interior magnetic field (the Meissner effect).

from Wikipedia

Superconductor

A conductor that exhibit superconducting properties. It is an assembly of low resistive metal and superconducting material.

Cryogenics

Cryogenic: for Greek "kryos", which means cold or freezing, and "genes" meaning born or produced.

"In physics, cryogenics is the study of the production and the behaviour of materials at very low temperature (<-150-180°C) "

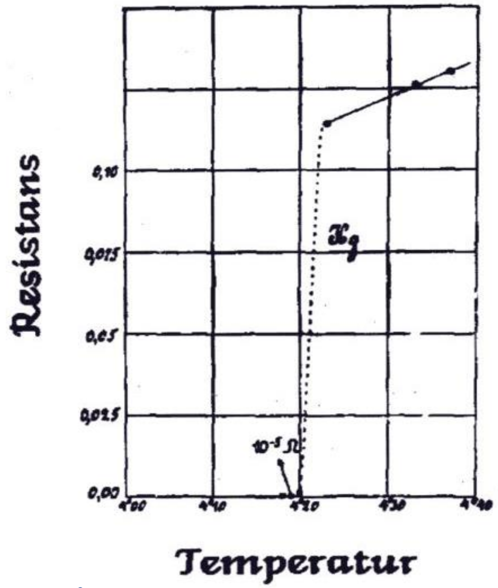
from Wikipedia

Main Properties of Superconductors

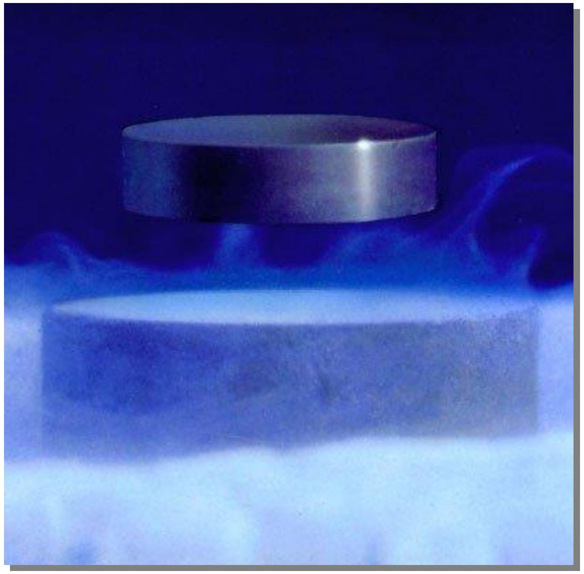
<u>For T<T$_c$</u>

Zero resistance ⇒ Perfect conductors

Exclusion of magnetic field ⇒ Perfect diamagnets



K. Onne's measurement on mercury (1911)



Discovered by Meissner and Oschenfeld (1933)

Perfect conductivity + perfect diamagnetism = superconductors

Various Superconducting Materials

Low Temperature Superconductors (LTS) T_c<39K

Pure metals

material	T_c,K	H_c,Oe	year
Al	1.2	105	1933
In	3.4	280	
Sn	3.7	305	
Pb	7.2	803	1913
Nb	9.2	2060	1930

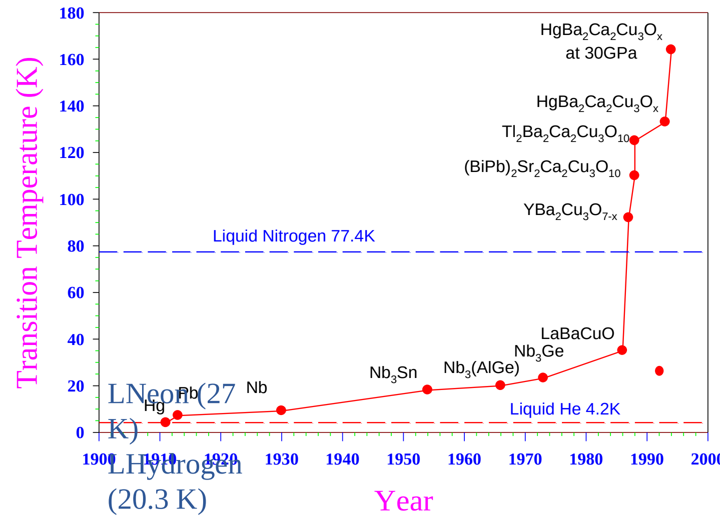
Alloys and Intermetallic compounds

	Tc (K)	Bc(T)
NbTi	10	15
V_3Ga	14.8	2.1
NbN	15.7	1.5
V_3Si	16.9	2.35
Nb_3Sn	18	24.3
Nb_3Al	18.7	32.4
$Nb_3(AlGe)$	20.7	44
Nb_3Ge	23.2	38

High Temperature Superconductors (HTS) T_c>39K

Cuprates

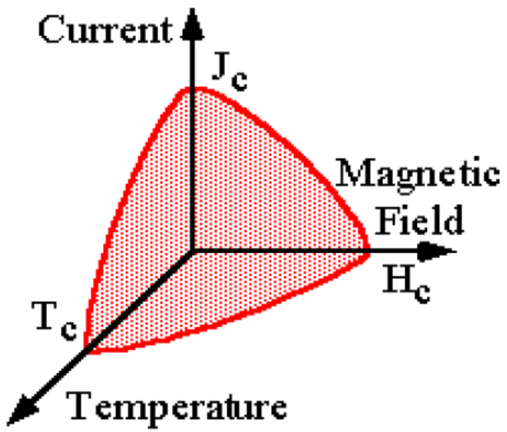
Compound		T_c (K)
$YBa_2Cu_3O_7$	Y(123)	93
$Bi_2Sr_2CaCu_2O_8$	Bi(2212)	92
$Bi_2Sr_2Ca_2Cu_3O_{10}$	Bi(2223)	110
$TlBa_2Ca_2Cu_3O_{10}$	Tl(1223)	122
$HgBa_2Ca_2Cu_3O_{10}$	Hg(1223)	133

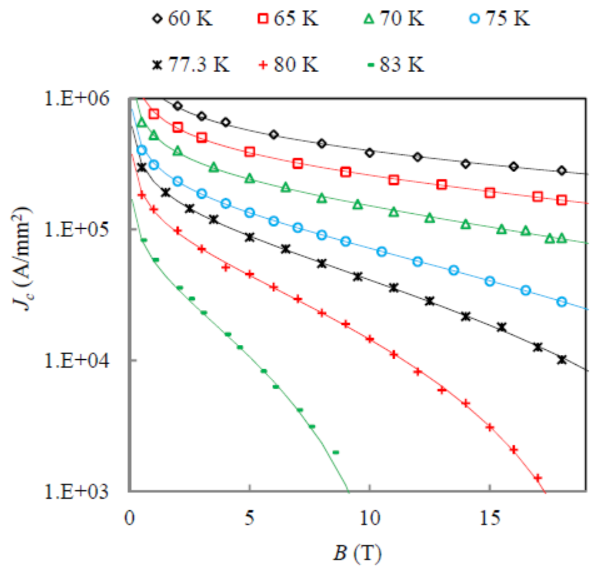


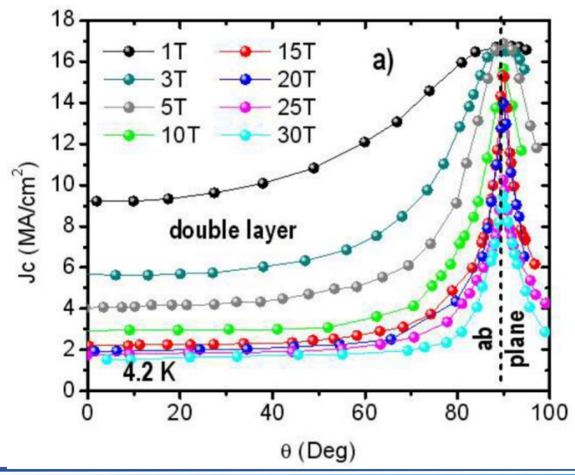
Phase Diagram of Superconductors

Main parameters of superconductors for magnets applications

- Critical temperature (T_c)
- Critical field (H_c)
- Critical current density (J_c)







Superconducting state if:

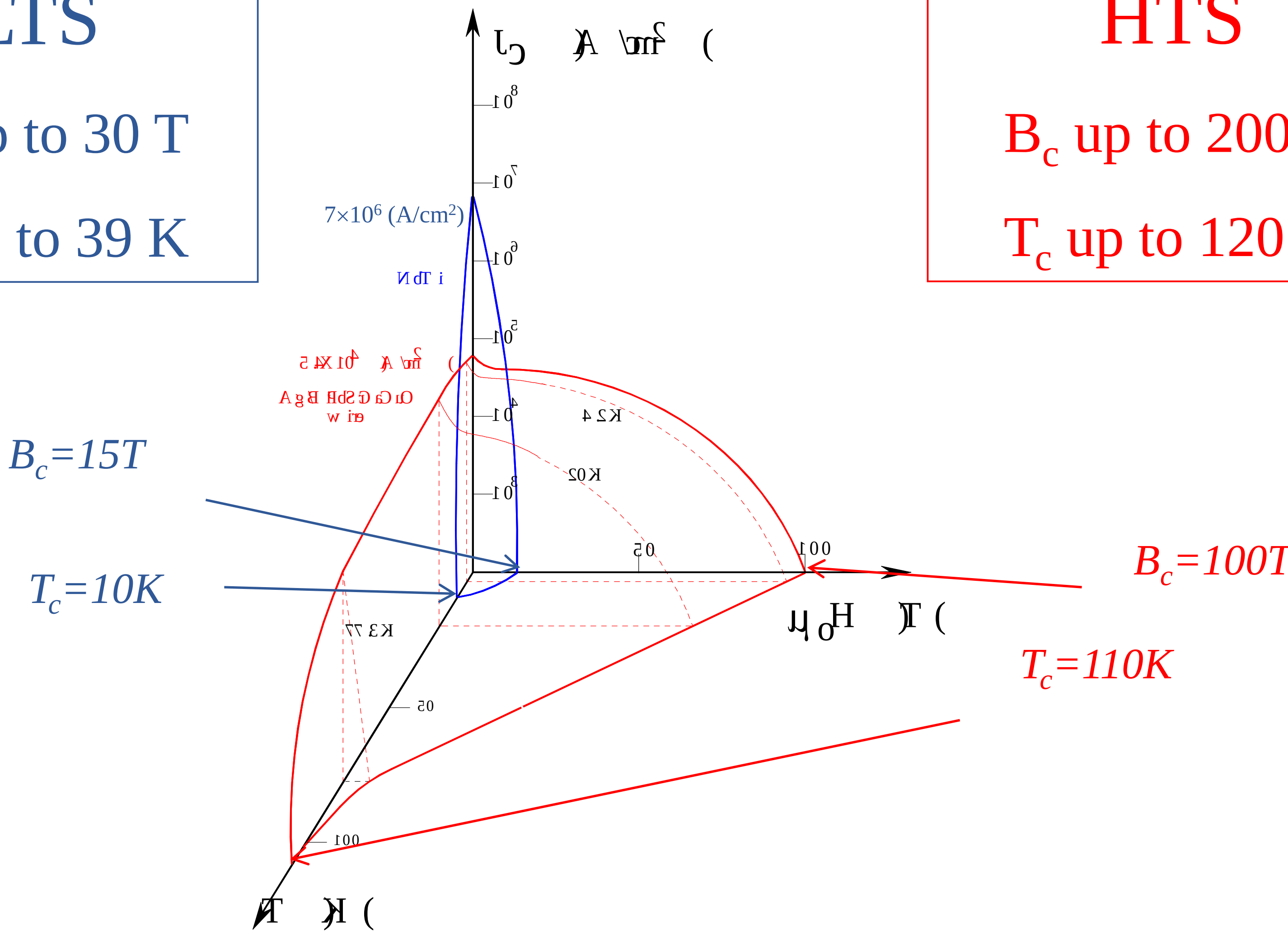
$T<T_c$

$H<H_c$

$J<J_c$

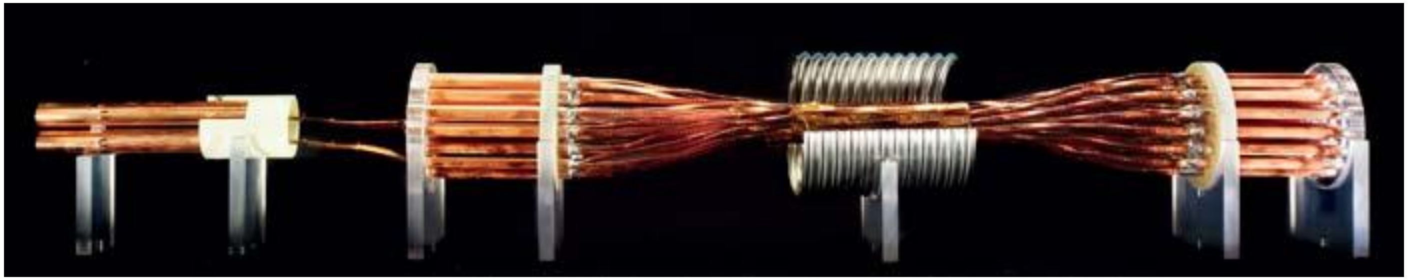
Phase Diagram of HTS versus LTS

LTS	HTS
B_c up to 30 T	B_c up to 200 T
T_c up to 39 K	T_c up to 120 K

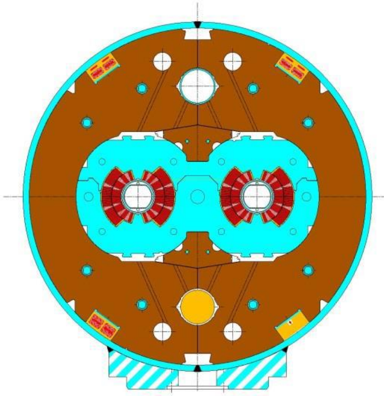


Superconductivity Applications

- **Generate high DC field**: (MRI, NMR, **particle Physics)**
- Current limiters
- Electronics, detectors (SQUIDS)
- Power transmission
- Magnetic levitation (Maglev)
- **Current leads**
- **RF cavities**



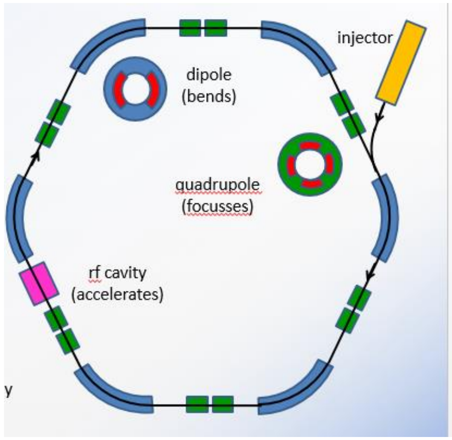
Superconducting devices in LHC



Magnets

More details in next slides

- **LHC ring magnets** (Nb-Ti): **Rutherford cables**
  - **1232** main dipoles: **8.3 T** x **15 m**
  - **392** Main quadrupoles **223 T/m (7 T)** x **4 m**
  - Zoo of **7600 others (cable or wire)**
- **LHC detector magnets** (Nb-Ti): **Rutherford cables**
  - ATLAS: Toroid **4 T, 25 m x20 m**
  - CMS solenoid: 4 T, **12 mx15 m**



Scheme from M.N. Wilson

Other devices

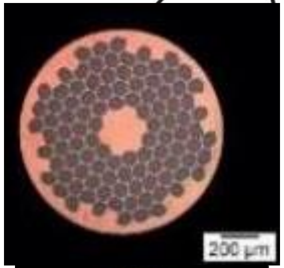
- **LHC current leads** (HTS BSCCO): stack of tapes
  - ~1000, rated for I ϵ[0.6,13 kA]
- **RF cavities (N_b coating)**

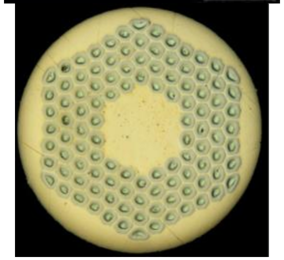
➢ **Superconductivity is a key technology of LHC**

Superconducting strands (for magnets)

Relevant parameters for accelerator magnets (Nb-Ti, Nb_3Sn..)

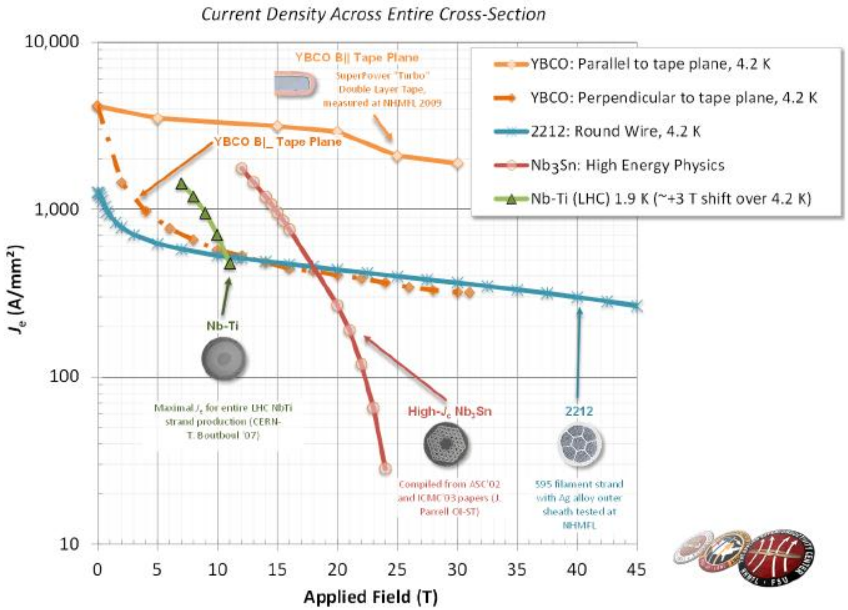
- Large overall current density ~**400–500 A/mm²**
- **Cu fraction** of about **50%** with **RRR >100**
- **Small filaments** to reduce magnetization and flux jumps
- **Twist** of the **filaments**
- Sufficient **mechanical properties** (axial and **transverse**)
- **Long** piece **length** (~1 km)
- **Good uniformity** of electrical performances
- …





Practical superconductors

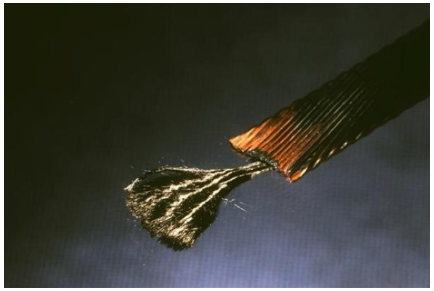
- **Nb-Ti** B_{0max}= **9 T**
- **Nb_3Sn** B_{0max}=**16 T**
- **REBCO** B_{0max}> **30T**
- **BSCCO** B_{0max}> **30T**

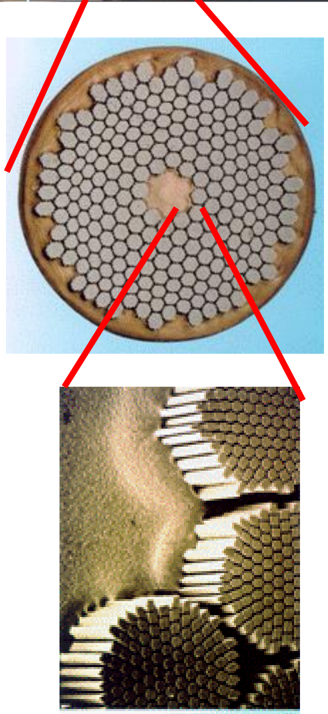


Beam energy: E [TeV]~**0.3 B**[Tesla] **R**[km]

Rutherford cables

- Why cables:
  - Needs for High current
  - Reduce piece length of conductor (~1 km)
  - Improve stability
  - Make easier the winding
- The use of large current cables implies also
  - to deal with dynamic effects
  - Less freedom for magnetic optimization
- Advantages of Rutherford cables (vs. other cables)
  - Good packing factor
  - Transposition of strands
  - Good control of dimensions (+/- 6 µm on thickness)
  - Good windability

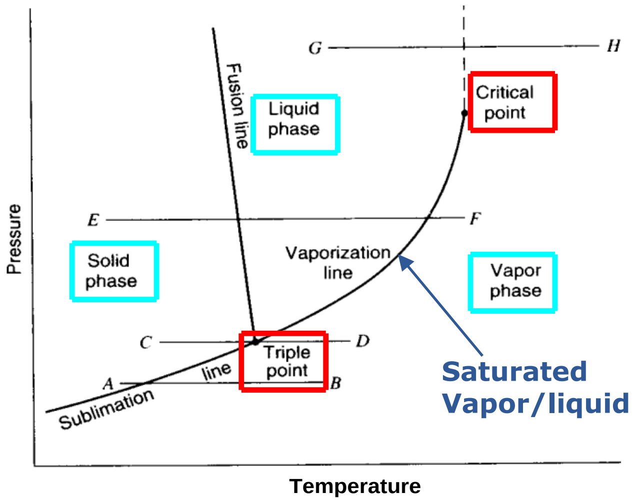




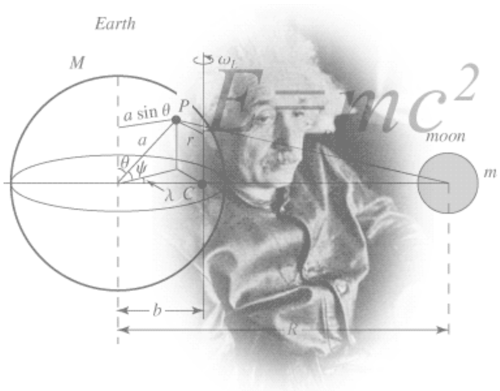
Superconductors needs Cryogens

LTS => Liquid Helium
HTS =>Liquid Helium or Liquid Nitrogen

	Triple point (K)	Boiling point (1 atm) (K)	Critical Point (K)
Methane	90.7	111.6	190.5
Oxygen	54.4	90.2	154.6
Argon	83.8	87.3	150.9
Nitrogen	**63.1**	**77.3**	**126.2**
Neon	24.6	27.1	44.4
Hydrogen	13.8	20.4	33.2
Helium	**λ-point**	**4.2**	**5.2**



In accelerator LTS are operated in liquid Helium bath



We will work with **cryogenics and superconductivity** to understand and verify the unique properties of superconductors

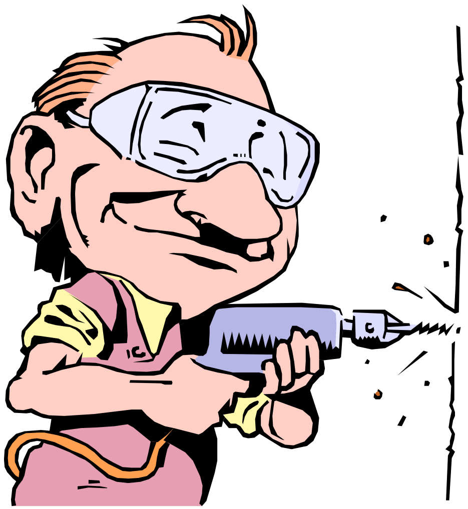
YBCO 123 bulk

BSCCO 2223 tape

SmCo, NeFeB magnets

Liquid nitrogen

………



Levitation

Flux pinning

Zero resistance

Jc,Tc,Hc

………

Experiments

Experiments will be performed with HTS superconductors

1. Levitation experiment
2. Critical temperature experiment
3. Zero resistance experiment
4. Critical current experiment

….

…

HTS → **Liquid nitrogen**

Superconductivity — Cryogenics

Superconductors you will use for the experiments at CERN:

- **YBCO** 123 Melt Textured Bulk .Tc= 93 K
- **BSCCO** 2223 Tape Tc= 110 K

You will use Nitrogen

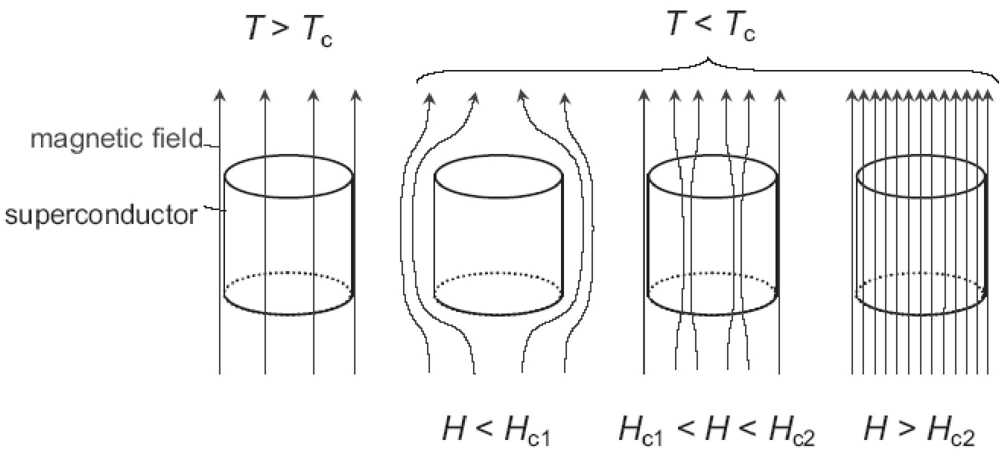
- 78% of atmosphere
- Boiling point (1 atm): 77 K (-196 °C)
- Colorless, odorless, non-toxic
- **Dealing with LN2: safety first (skin burn, splashing..)**

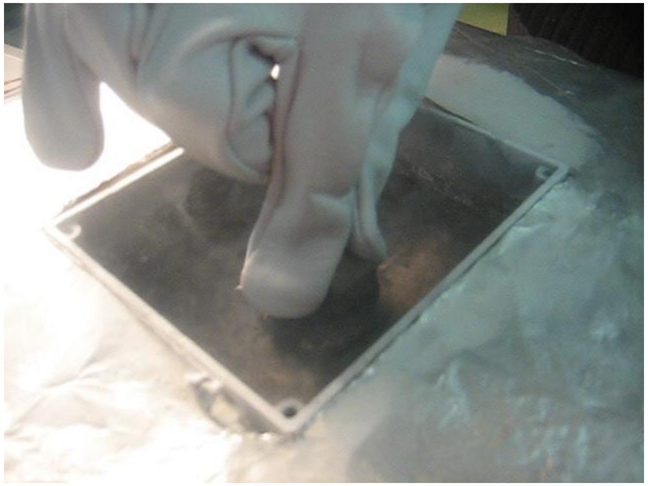
0.2

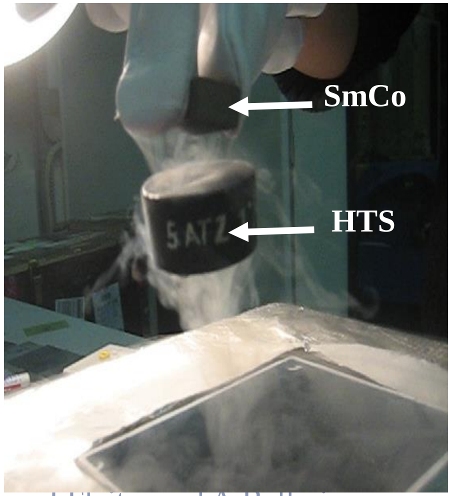
4 mm

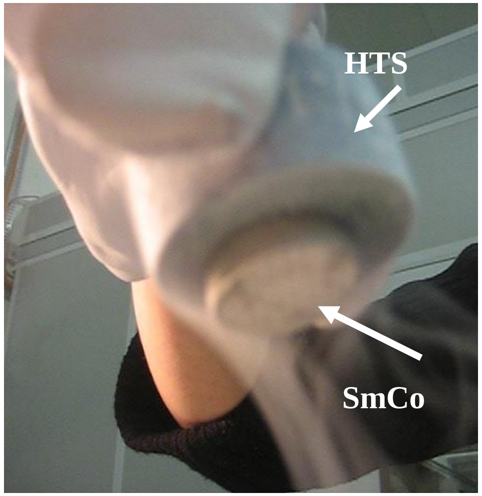
Levitation experiment

- Understand the Meissner effect and flux pinning
- Appreciate the intensity of the levitation force !





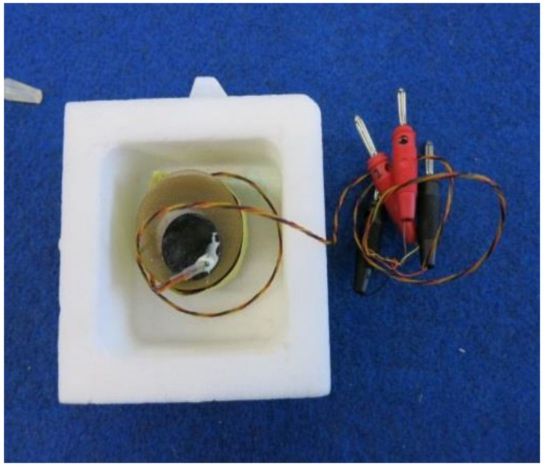


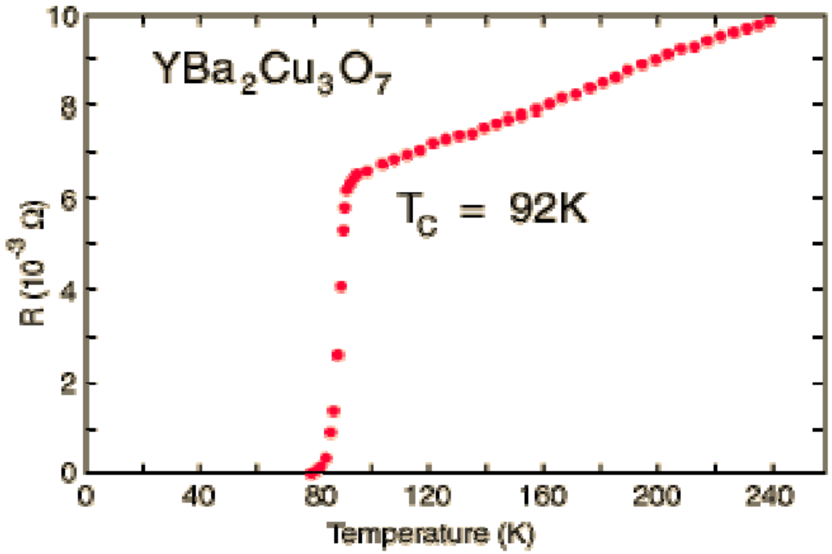


Levitation experiment

Critical temperature experiment

Measurement of critical temperature by using the Meissner effect.





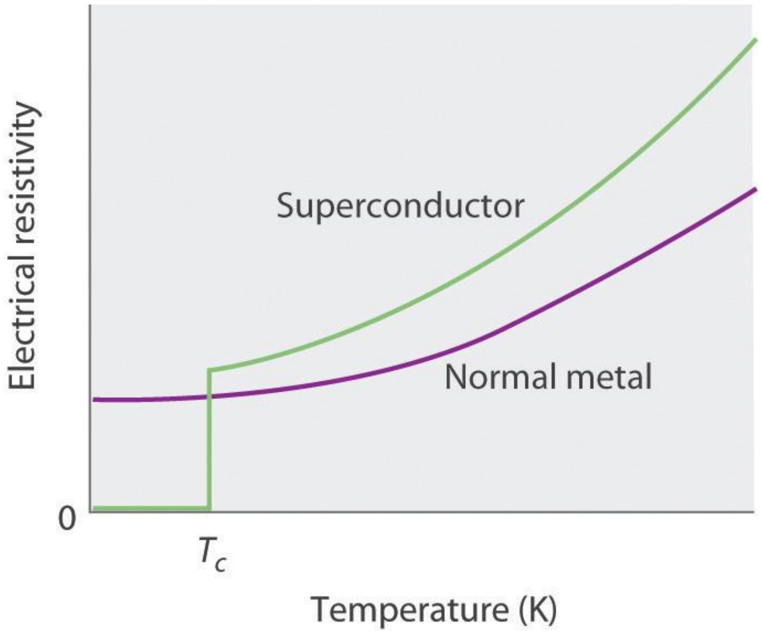
The critical temperature is defined as the temperature measured on the superconductor when the permanent magnet levitating on it comes to complete rest on the superconductor's surface.

Critical temperature experiment

Zero resistance measurements

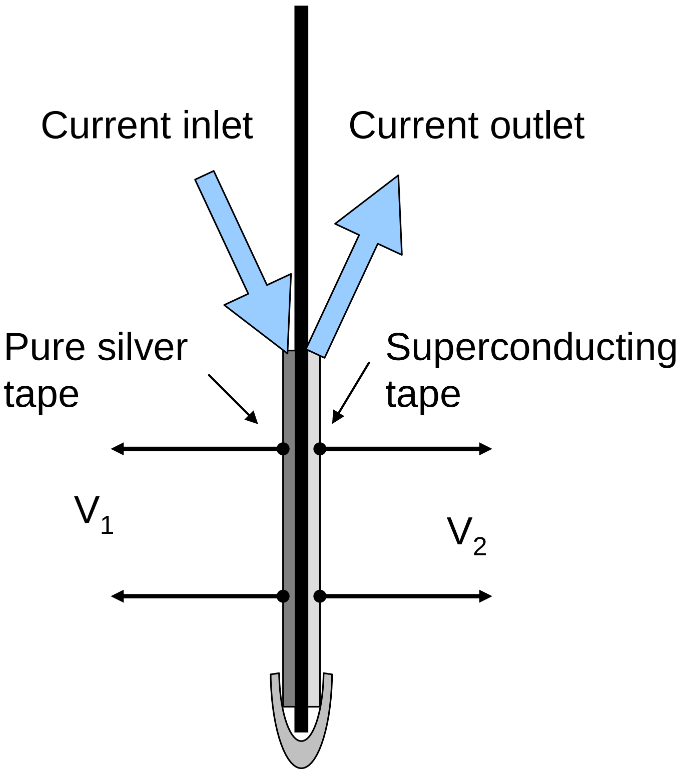
Experiments were performed on the current decaying in a superconducting loop ($\rho < 10^{-26}\ \Omega \cdot m$).

	$\rho(\Omega \cdot m)$
Insulators	10^{20}-10^{10}
Semiconductors	10^{5}-10^{-3}
Metals	10^{-5}-10^{-10}
Superconductors	~ 0

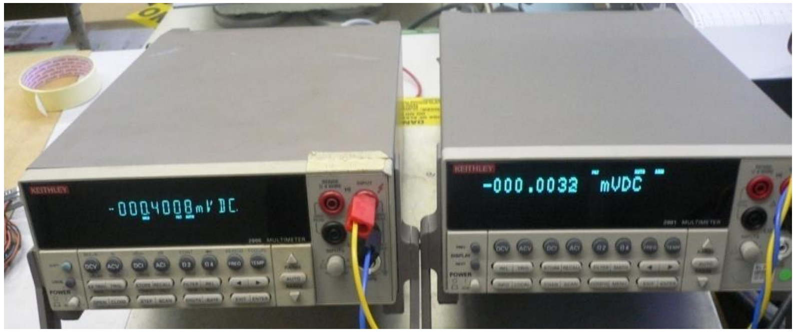


True only in the superconducting state

Zero DC resistance experiment



A superconducting tape and a pure silver tape are connected in series, Measure the voltages (resistances) as the specimens are inserted into liquid nitrogen and cooled to 77 K.



ρ_{Ag}(293 K)~1.46·10^{-6} Ω·m
ρ_{Ag}(77 K) ~0.2· ρ_{Ag}(293 K)

A see-through glass walled dewar is used for the LN_2.

HTS:BSCCO 2223 multi-filamentary tape in silver alloy matrix.

DC Critical current experiment

Critical current (**I**$_c$): current at which a specified electric field criterion E_c, or resistivity criterion ρ_c is achieved in the specimen. Losses through a Type II superconductors ($H_{c1}<H<H_{c2}$) depend on the sample geometry and on the vortex pinning.

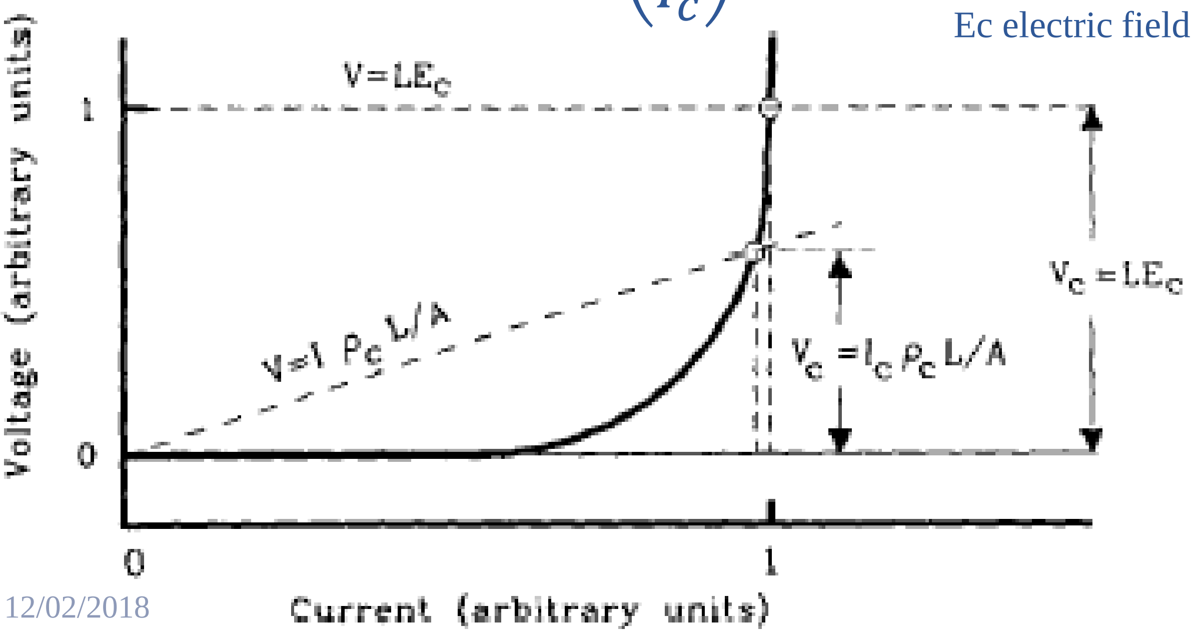
$$E = E_c\left(\frac{I}{I_c}\right)^n$$

n=n-value (-)

Ic critical current (A)

E electric field (V/m)

Ec electric field criterion (1 uV/cm)



H=const

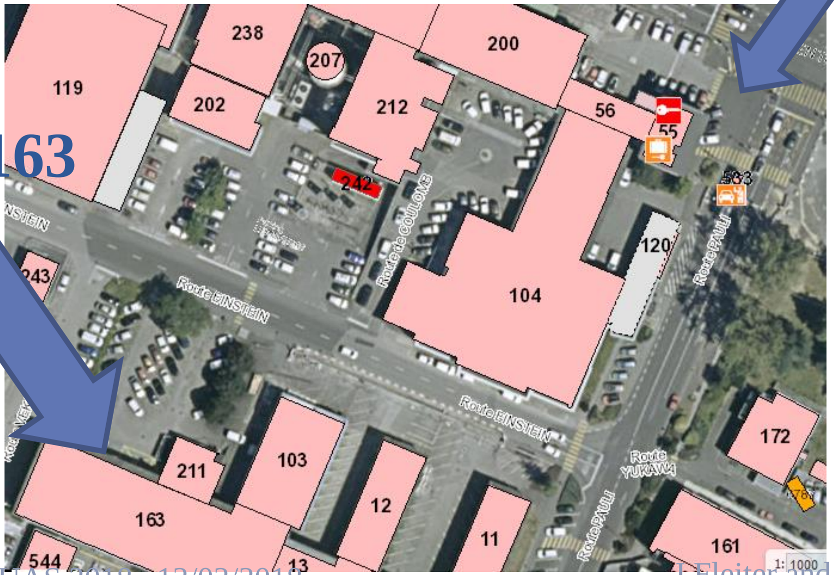
T=const

Program and Organization (1/2)

- **Up to 12** participants per day
- Hands-on **practical work** in CERN laboratories
- Guided by **experts**
- **When** ? On the 1st and 2nd of March
- **Where** ? In the Superconductor Laboratory, Building 163

Main entrance

B. 163



Program and Organization (2/2)

Practical work in building 163

Visit of Superconductor Laboratory, Building 163

Test stations for the measurement of:

- **Critical current** of superconductors (strands and cables) at liquid He temperature (1.9 K and 4.2 K, up to 15 T and up to 32-70 kA);
- **Magnetic properties** of superconductors (magnetization curves) at variable temperatures and fields (VSM);
- **Electrical Resistivity** as function of temperature;

Cabling machine for accelerator Rutherford cables;

Visit of Laboratory, SM 18 :Test stations for magnets

We are looking forward to

working with you at CERN !