Superconductivity

Practical Days at CERN

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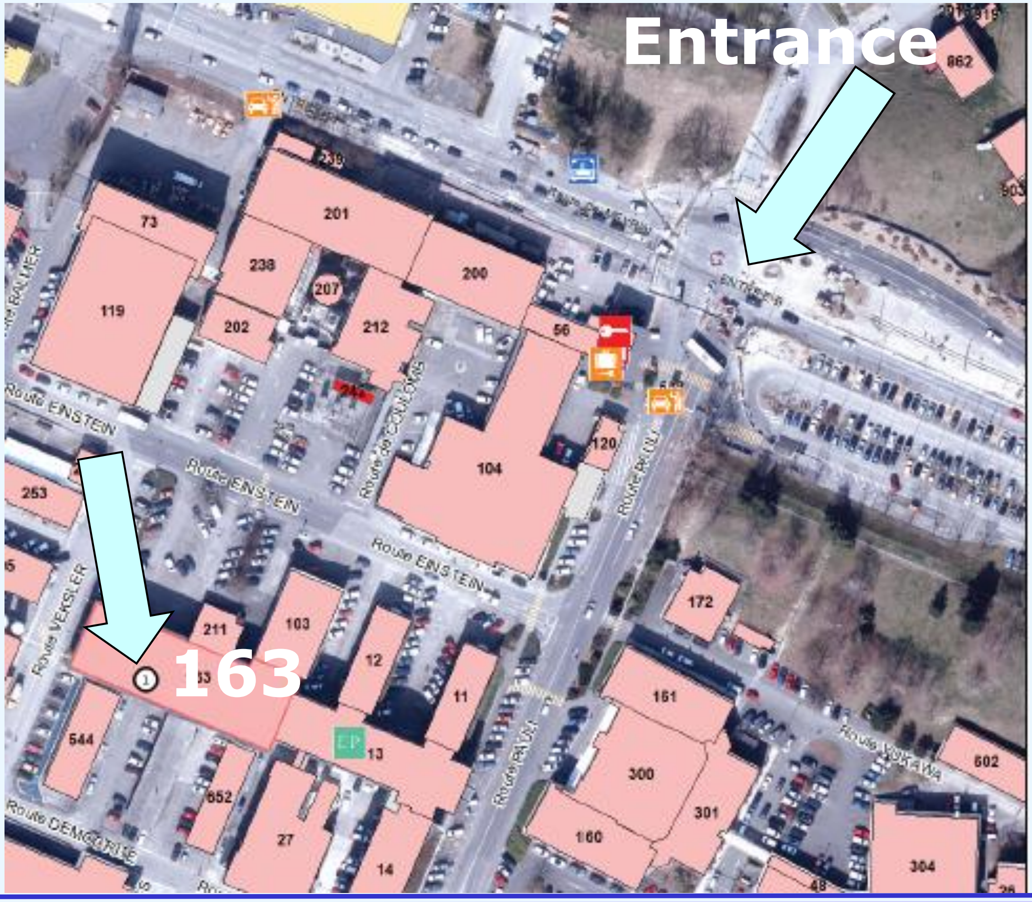
Practical Days at CERN

When ? On the 21st of February

Where ? In the Superconductor Laboratory, Building 163

Group of max 6 persons



Practical Days at CERN

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 35 kA);

Magnetic properties of superconductors (magnetization curves) at variable temperatures and fields (VSM);

Residual Resistivity Ratio, **Resistivity** as function of temperature;

Cabling machine for accelerator Rutherford cables;

Laboratory for **analysis** of superconductors;

Nb-Ti, **Nb_3Sn**, **YBCO**, **BSCCO 2223** and **MgB_2** strands and cables

Visit of laboratory SM-18

Practical Days at CERN

What will you do ?

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

Superconductivity → Cryogenics

Superconducting materials

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

pure metals

HTS

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

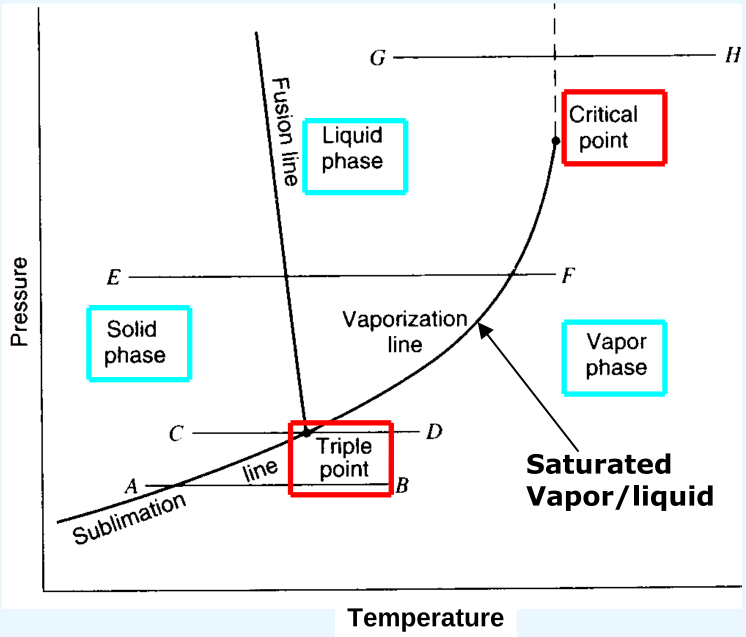
LTS

	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

MgB_2 (Tc=39 K)

Cryogens

	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



Nitrogen

- 78% of atmosphere (21% oxygen, 1% water vapor, carbon dioxide, argon,…).
- Discovered in 1772 by Daniel Rutherford in his attempts to isolate oxygen and carbon dioxide from air.
- Colorless, odorless, non-toxic. The liquid is similar in appearance to water.
- Boiling point (1 atm): 77 K (-196 °C). It is colder than liquid oxygen (boiling point = -183 °C): oxygen in the air condenses out.
- Critical temperature: 126 K (-147 °C).
- Latent heat of vaporization: 197 J/g. 1 W boils off 22.5 cc/hour.

➢Volume of **expansion** liquid to gas (15 °C, 1 atm): **682**. One volume of liquid nitrogen expands to produce 682 equivalent volumes of gas! Closed containers very likely burst.

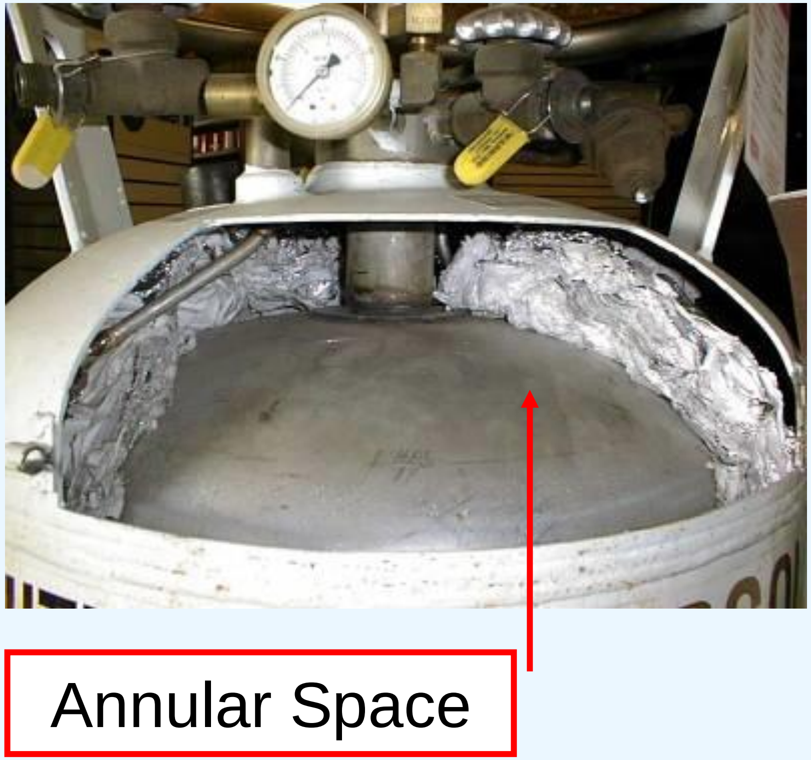
1 liter LN_2  ⟶ 3 ×  GN_2

Standard liquid nitrogen dewars:150-200 liters….

➢Relative density (gas): 0.97 (air=1), <u>but</u> at room temperature very cold gas will be heavier than air. Cold nitrogen gas boiling off from the liquid state stratifies in the low areas.

Liquid nitrogen (LN_2)

- LN_2 is stored in <u>vacuum insulated</u> storage vessels (dewars), with a vacuum space and a special thermal insulation. However, leaks into the vessel cause the cryogenic liquid to vaporize and build up pressure. In optimum conditions, the liquid-to-gas conversion rate per day is about 2.3 %.
- Pressure relief valve to protect the vessel against over-pressure.
- Level gauge.
- Rupture disk.



Dealing with LN_2: safety first

Like other cryogens, **may be harmful if not handled properly!**

The extremely low temperature of the liquid nitrogen (LN_2) can cause severe **burn-like damage to the skin** either by contact with the fluid, surfaces cooled by the fluid or evolving gas.

Skin can freeze and adhere to LN_2 cooled surfaces causing tearing on removal. Thermal gloves must be worn when handling objects cooled by LN_2 (transfer lines, test materials,…). DO NOT touch cold surfaces with bare hands to avoid severe cold-burns !

Boiling and splashing will always occur when filling a warm container. Protection glasses must be worn.

Dealing with LN2: <u>safety first</u>

Nitrogen can easily replace air in poorly ventilated areas (**risk of asphyxiation**).

Many **materials** (common glass, plastics, iron…) become brittle and may **shatter** when cooled in LN_2.

Oxygen condenses and collects on objects cooled in LN_2 (nitrogen smokes, but you should not do it in his presence !).

Preferably wear long trousers and avoid wearing metallic objects (watches, rings, bracelets…) that could injure your body or get damaged (magnetic fields and cryogens).

Experiments

1. Levitation experiment

    Field-cooled and Zero Field cooled

    Measurement of levitation force

2. Flywheel demonstration

3. Critical temperature experiment

4. Zero resistance experiment

    Resistivity of metals and superconductors

5. Critical current experiment (V-I curve of superconductors in self-filed and in external field))

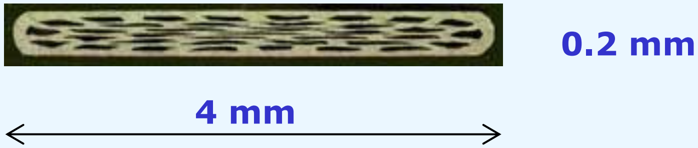
6. Resistive transition experiment (quench)

7. Optical microscopy analysis of composite superconductors

A few examples

Critical current experiment (self-field)

BSCCO 2223 multi-filamentary tape



T=77 K
Self-field

E_c= 1 μV/cm
Measure I_c in liquid nitrogen.

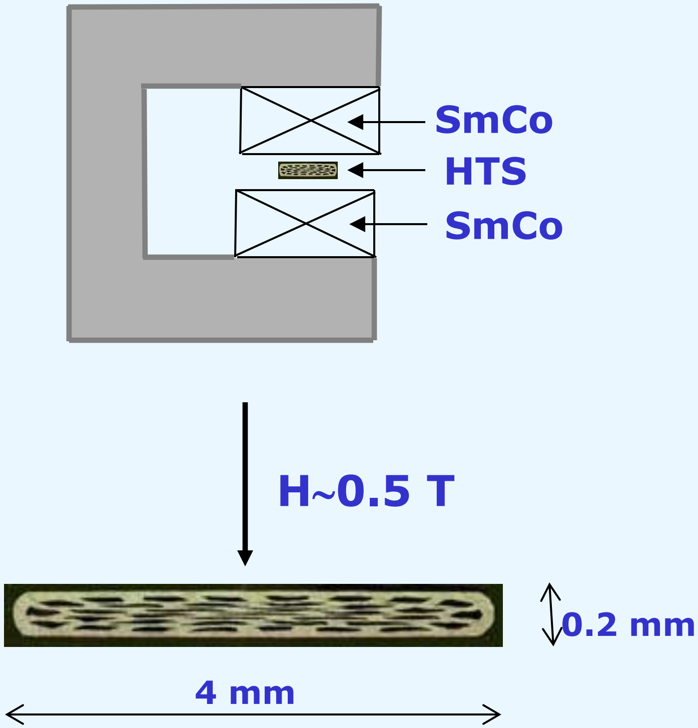
f=filling factor=A_{HTS}/Atot
f=40%

Derive

Jen (Engineering critical current density=current over the total cross section of the tape) and
Jph (Physical critical current density=current in the HTS).

Critical current experiment (external field)

T=77 K

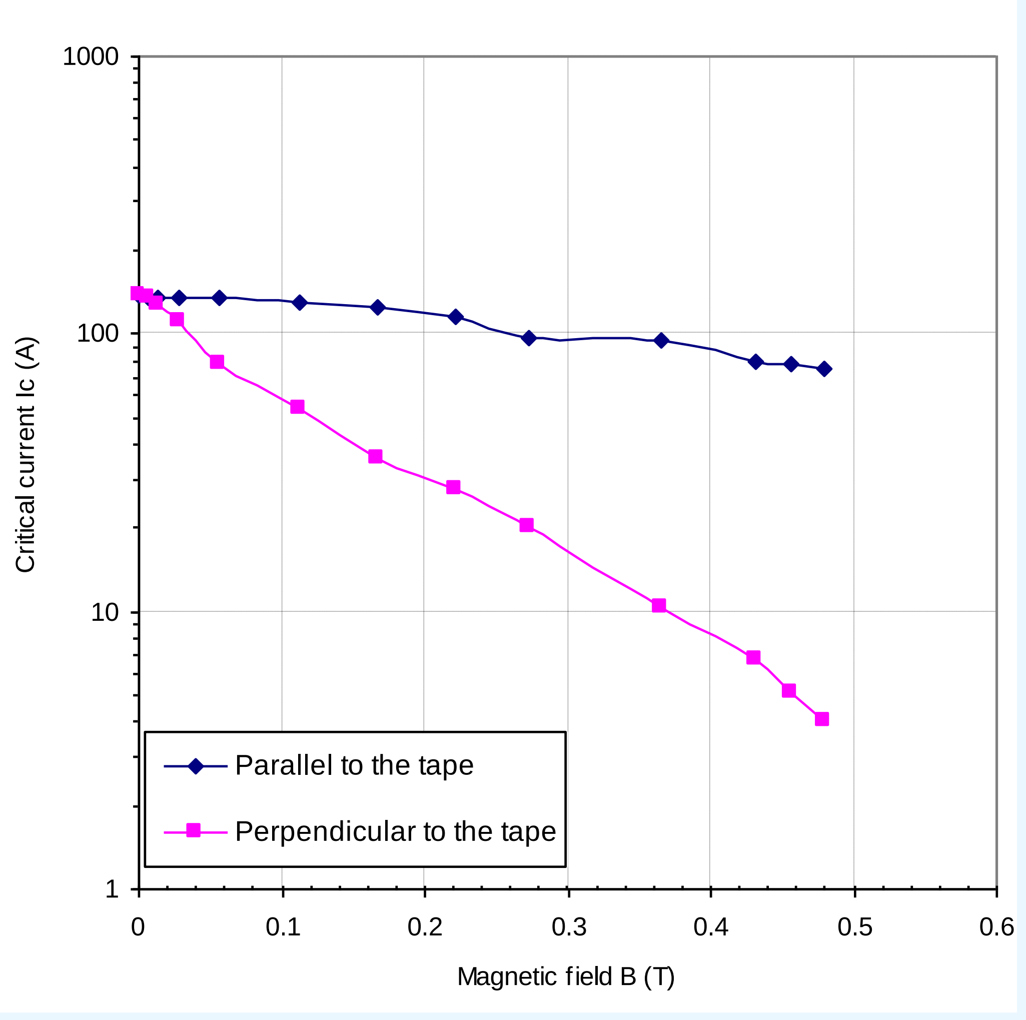


Magnetic circuit with rare-earth permanent magnets assembled in a C-shaped iron yoke.

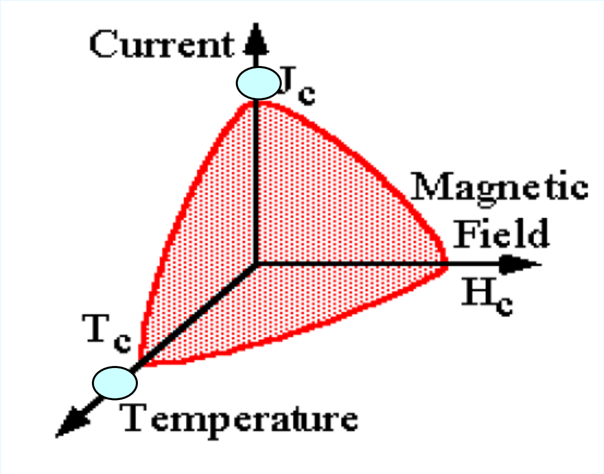
Orientation of field is important, because HTS materials are higly anisotropic.

SmCo surface's strength=0.38 T → ~10000 the earth's magnetic field !

I-B curve measured on a BSCCO 2223 tape (77 K)



What about a resistive transition?



We will work outside of the critical surface by:

1) Increasing the current at 77 K;
2) Increasing the temperature at constant current.

In both cases, we will assist to an irreversible transition of the superconductor: the BSCCO 2223 will burn (E>>1 μV/cm).

And you will see it….

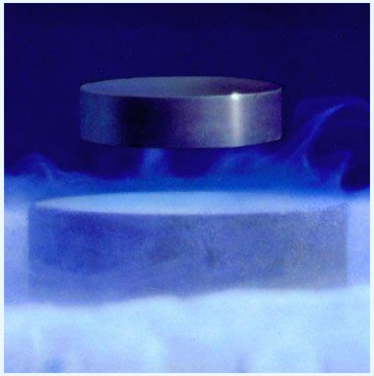
If superconducting materials "quench", they need protection!

Field-cooled experiment

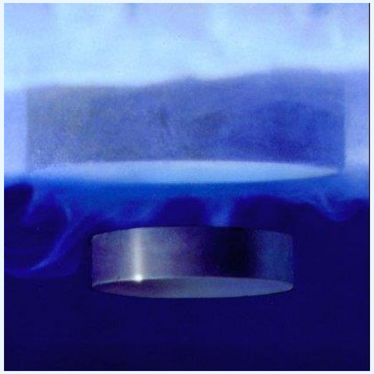
Magnetic flux expulsion (levitation) → Meissner effect.
But:

Combination of Meissner effect repulsive force and flux pinning restorative force causes stable levitation.

Levitation…



…can become suspension



The vertical magnetic force can become attractive *or* repulsive depending upon the sign of the magnetization.

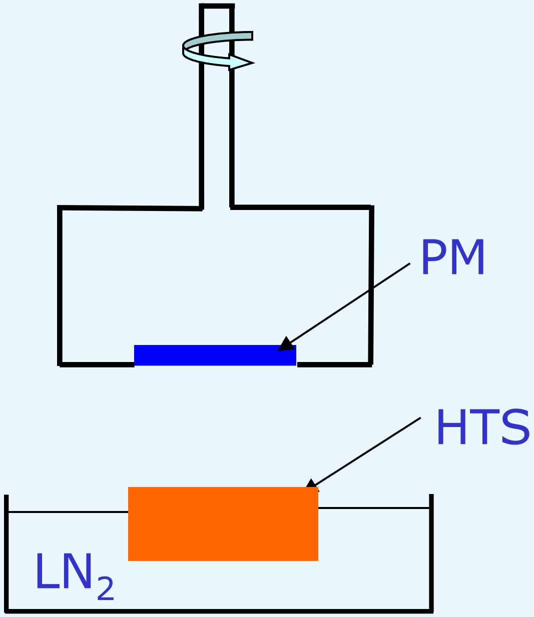
Flywheel demonstration

Flywheel energy storage system is used to store electricity as kinetic energy and to convert it to electricity when needed.

It consists of:

Rotor – magnet (PM) – motor and generator (room temperature).

HTS magnetic bearing (LN_2).



$$E=1/2 \cdot I \cdot \omega^2$$

We are looking forward to

working with you at CERN !