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Measuring and analyzing the resistivity break down of high temperature superconductors in a didactic laboratory

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Summary. — The behavior of superconductors manifested especially when measuring resistivity versus temperature above and below the critical temperature still appears as extremely interesting phenomena. The paper describe a several measurements preformed at didactic laboratory which demonstrate different superconductors' behavior and could be used as an introduction to further investigations. Comparison with models is shown as well as further important remarks for work planed for future are made.

PACS 01.50.-i – Educational aids.
PACS 01.50.F- – Audio and visual aids.

1. – Introduction

The behavior of resistivity versus temperature for superconductors above and below the critical temperature gives the opportunity to characterize and distinguish the different types of superconductors. The observations could be used to explore several of phenomenological properties as the hysteresis, the broadening of the resistive transition in presence of external magnetic field and to test microscopic model extracting relevant information on the processes governing the superconductive phase. Moreover performing Hall coefficient measurements it is also possible to characterize the non-Fermi liquid behavior of some high temperature superconductors.

Using the USB data acquisition system developed in the European project MOSEM (Greczyło 2008) we are able to explore the phenomenological behavior of superconductors also in a didactic laboratory. The resistive transition is well characterized recognizing for instance the sharp but hysteretic behavior in low fields, the appearance of one or more shoulders (vortex slush). Other opportunities offered by the system are the exploration of the broadening of the previous features in applied magnetic fields (Lorentz force driven dissipation) and the appearance of a paramagnetic-ferromagnetic transition. In the paper we present just some examples of measurement together with examples of fits with model data.

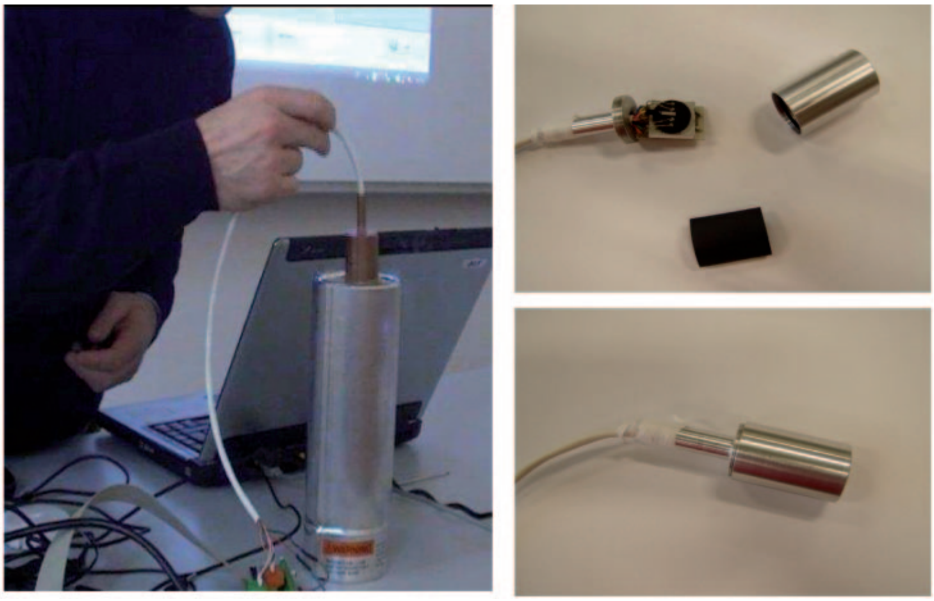

Fig. 1. – The USB data acquisition system—view when inserting probe in to a liquid nitrogen dewar, inside and outside outlook of the sample.

2. – The experimental apparatus

The measurements are carried out with a didactical apparatus developed in the framework of the European project MOSEM and consisting of a USB interface, a 4-point superconducting sample and the user-friendly software. The USB probe is designed to allow measuring of resistivity *versus* temperature in metal, superconductor and semiconductor solids and a combined room temperature Hall coefficient measurement for metals and semiconductors. The resistivity measure can be carried out in the 78–400 K temperature. High quality measurements give the opportunity to fit data with curves based on theoretical models (Gervasio 2009).

3. – Resistivity *versus* temperature measurements for YBaCuO superconducting samples

The measurements were conducted with the use of two cylindrical samples of diameter $d = (20 \pm 1)$ mm baked from YBaCuO powder purchased at Aldrich. The samples differ in:

- temperature of transition T_t,
- resistivity at room temperature R_0,
- thickness—sample 1 $l_1 = (3.5 \pm 0.5)$ mm; sample 2 $l_2 = (5 \pm 0.5)$ mm.

Thanks to the USB data acquisition system we were able to recognize the difference of only 3 K in the critical temperatures T_t for both samples, as well as notice the different values of their resistances at room temperature R_0.

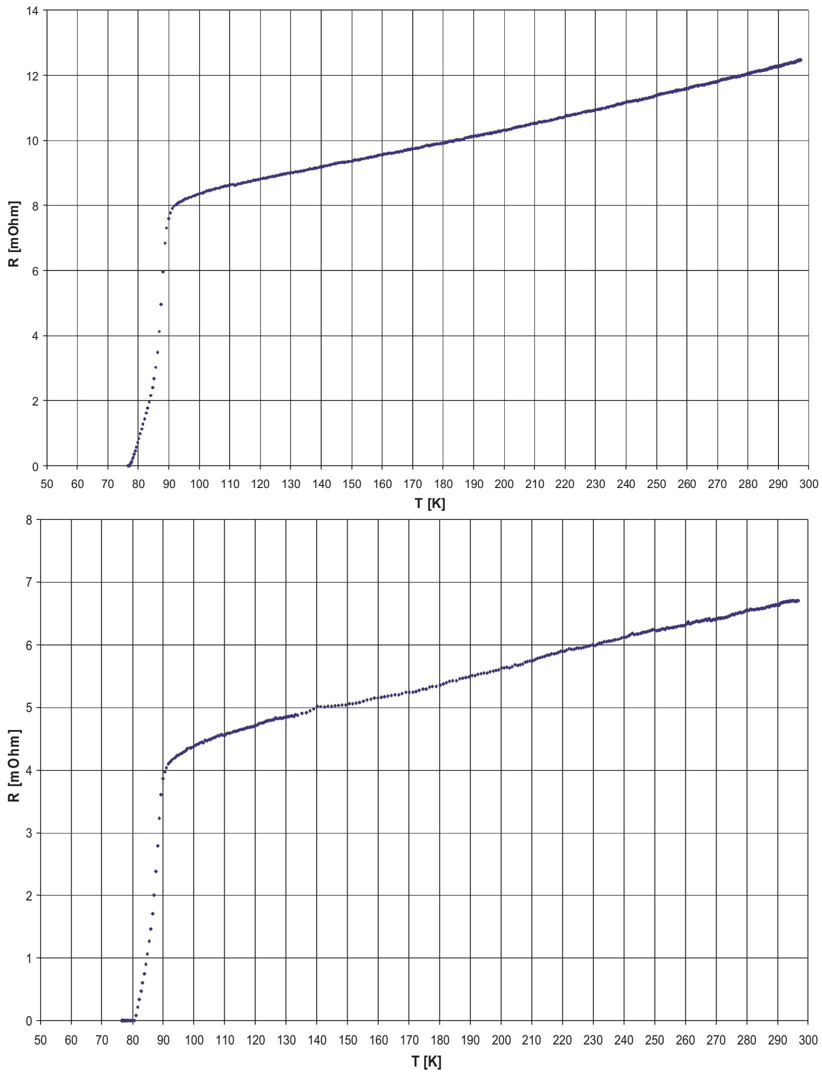

Fig. 2. – Free warming up for sample 1 (upper graph) and sample 2.

Figure 2 shows resistivity versus temperature behavior for both samples when they were warmed up freely from liquid nitrogen temperature up to room temperature. From the data represented in those graphs we obtained values for T_t and R_0 and compare them with nominal data. The results are reported in the table I.

In spite of the hysterias noticed when each sample was cooled down and then warm up equal in uncertainty borders values for T_c and R_0 were obtained for both samples

Figure 3 shows the hysterias for the sample 1 only. To give scientific interpretation of the evidenced hysteresis on advanced level more accurate data are needed. We plane to perform additional measurements and deeper experimental analysis in future.

3˙1. *Comparison between the two samples.* – Figure 4 shows the curves presented in figs. 2 at one diagram together with comparison of the liner fits for $T > T_t$. It presents

TABLE I. – *Temperature and resistivity values for both samples.*

	$T_{t\,\mathrm{meas.}}$ [K]	$T_{t\,\mathrm{nom.}}$ [K]	$R_{0\,\mathrm{meas.}}$ [mΩ]	$R_{0\,\mathrm{nom.}}$ [mΩ]
Sample 1	102 ± 0.5	102–104	11.5 ± 0.5	12.5 ± 0.5
Sample 2	101 ± 0.5	101–102	6.5 ± 0.5	6.7 ± 0.2

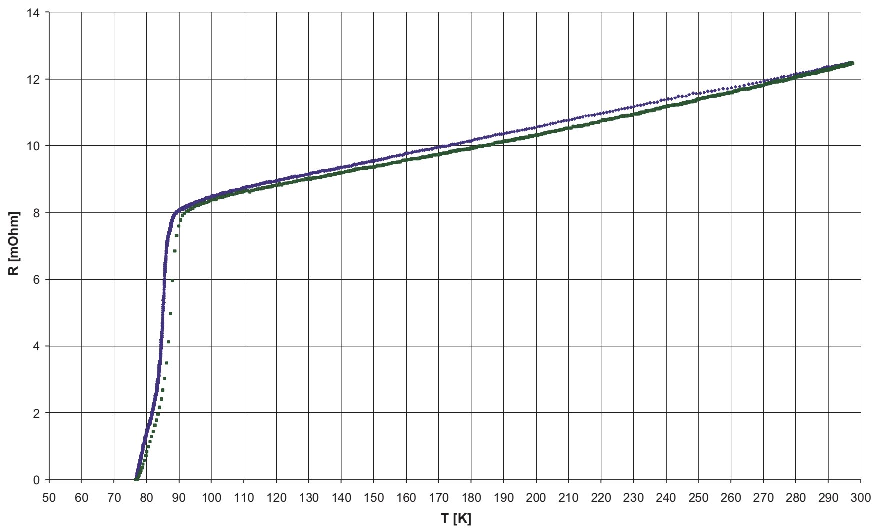

Fig. 3. – (Colour on-line) Free cooling down (blue) and warming up (green) for sample 1.

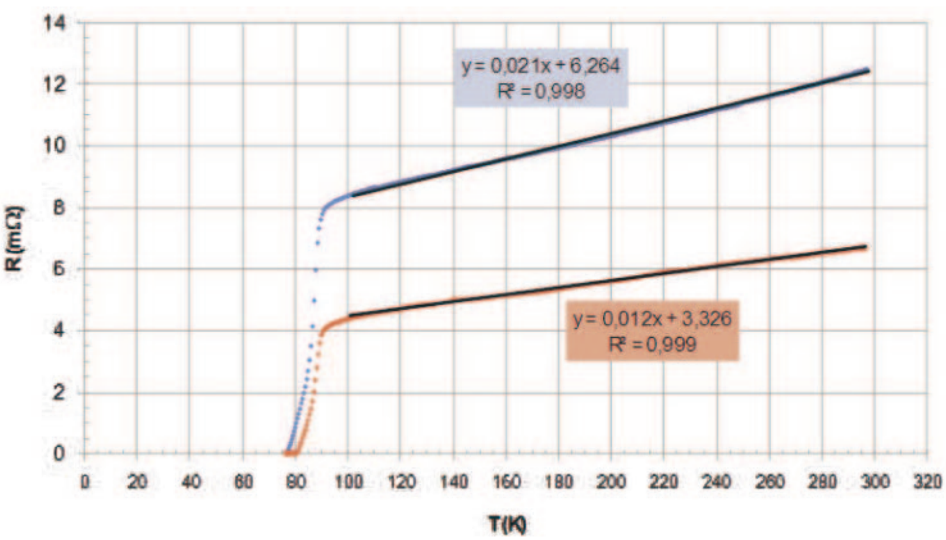

Fig. 4. – Samples' compression and fitting.

the double slope of the $R = R(T)$ curve for the sample 1 with respect to the sample 2 which gives following values – $0.021\,\mathrm{m}\Omega\,\mathrm{K}^{-1}$ and $0.012\,\mathrm{m}\Omega\,\mathrm{K}^{1}$. A superlinear behavior is also observed for the sample 2 curve. The linear fit of the logarithmic graph give value $A = 1.07$ appearing in $R - R_N = A\ (T - T_t)$ where R_N represents resistance at the transition temperature. To analyze the behavior for $T < T_t$, for each of the two samples we plot the dependence of R/R_N *versus* $T - T_t$ and then we made a comparison with model proposed in literature—see fig. 5 for details.

In both cases the curves calculated according to model proposed by Strbik *et al.* (1990) and Tinkham (1988) are qualitatively in agreement with the experimental data. The obtained results lead to suggestion of using the quasi equilibrium measurements procedure. This way of measuring is supported in the data acquisition system developed in the MOSEM project and authors believe that will allow obtaining more significant results in future.

3·2. *Phase transition in presence of an external magnetic field.* – Figure 6 shows parts of the experimental apparatus to carry out the measurement giving data necessary to construct the $R = R(T)$ curves in presence of an external magnetic field. The samples are inserted between two polar expansions producing a magnetic field of intensity from 0 to about 1 T depending on the distance of the polar expansion.

In figs. 7 to 9 we present test measurement results in which compression of resistivity versus temperature curves when field $B_{ext} = 0$ and $B_{ext} = 0.22 \pm 0.02\mathrm{T}$ is offered. Based on reported observations made when the magnetic field is applied following remarks can be stated:

– the presence of more evident hysterias is noticed when cooling down and then warming up the very same sample,

– the resistivity did not drop to zero at the same temperature as in a case when $B = 0T$,

– only in some cases a para-ferro magnetic transition is observed,

– the slope of the curves decrease when increasing the magnetic field.

For both values of magnetic field applied we observed a different slope of curves, a cross of the two curves and the decreasing of the value at which the resistivity became zero. The first two observations are not in agreement with literature data, when the third is mentioned in scientific papers (Cohen 1997), (Woch 2004), (Butch 2008).

4. – Conclusions

The paper presents and describes a preliminary – test experimental data which unquestionably illustrate the new opportunities opened in the didactic laboratory by use of USB date acquisition system. The system allows registration of temperature and resistivity values for varies samples in a wide range of valuables. Significant results obtained thanks to the use of setup characterize different types of superconductors evidencing—among other foundlings—differences in the temperature transition—the slopes of the

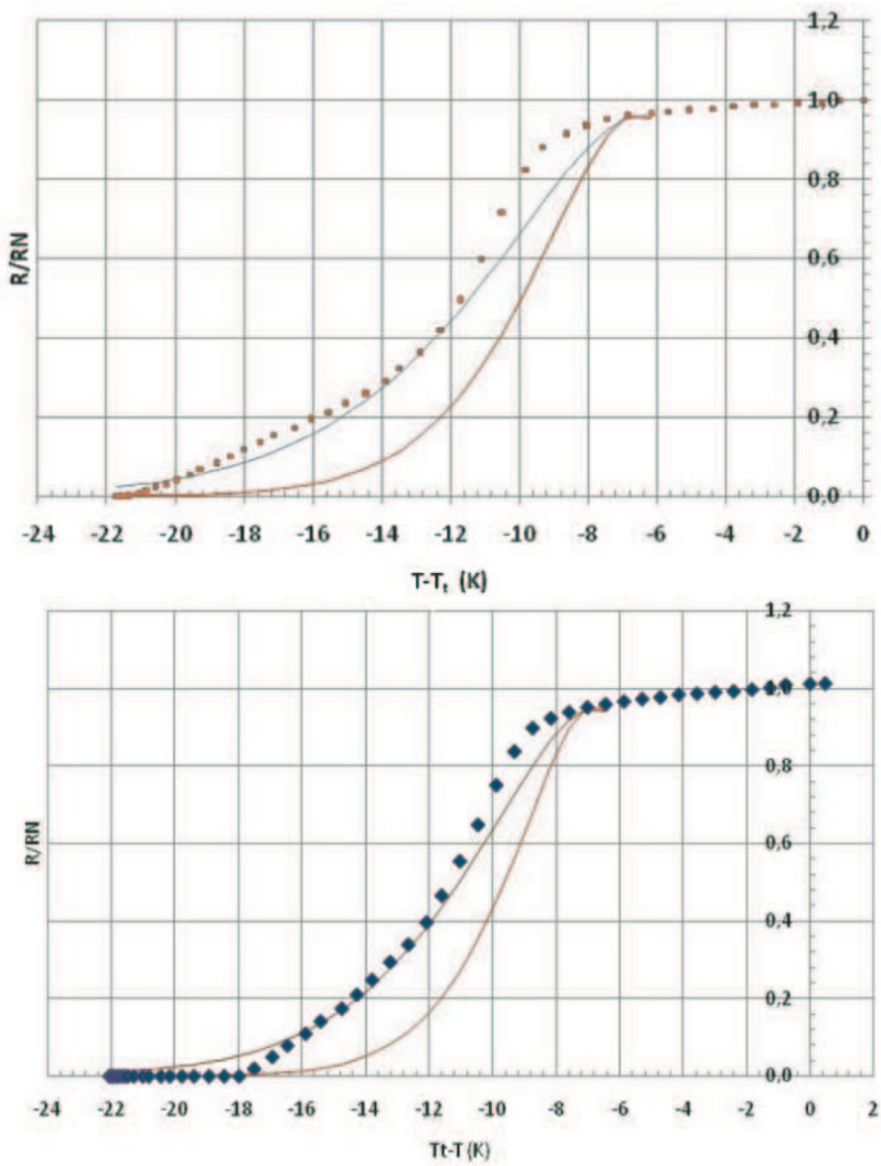

Fig. 5. – (Colour on-line) Comparison of experimental data with model curves proposed by Strbik (blue line) and Tinkham (red line) for sample 1 (upper graph) and sample 2.

$R = R(T)$ curve. Interesting from scientific point of view results may also be registered when the magnetic field is applied. Approaches based on quantitative analysis of the phenomenology and related modeling activities are possible due to the described setup. Supporting qualitative exploration and construction of a theoretical framework are now possible even at school level.

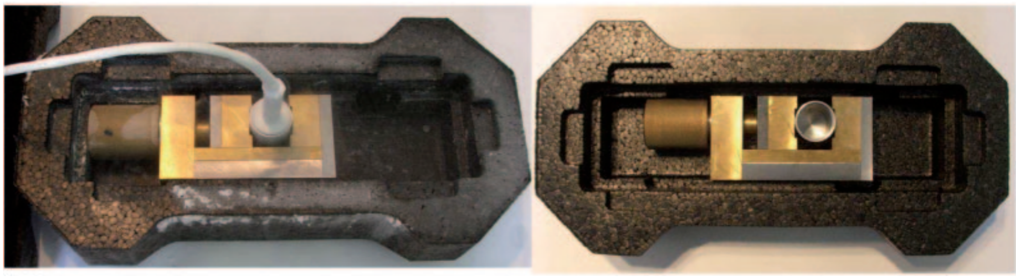

Fig. 6. – View of apparatus to apply magnetic field to the samples under study.

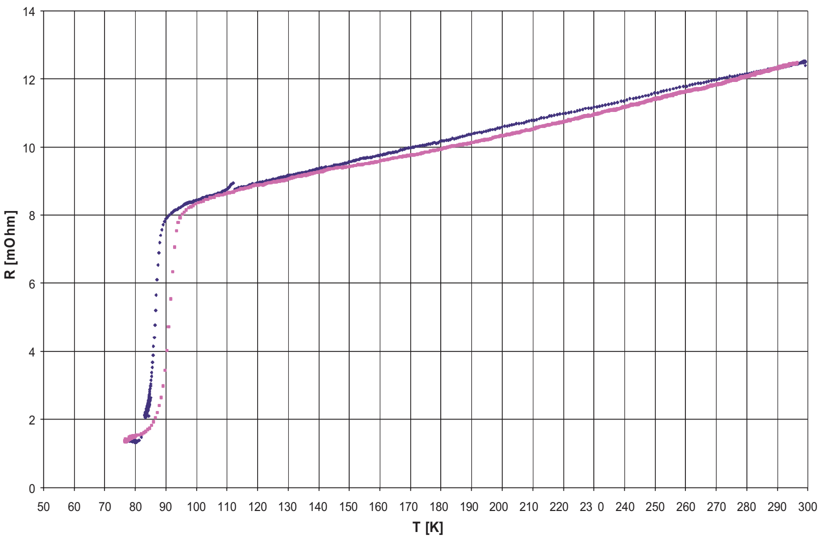

Fig. 7. – (Colour on-line) Free cooling down (blue) and warming up (pink) when magnetic field applied for sample 1.

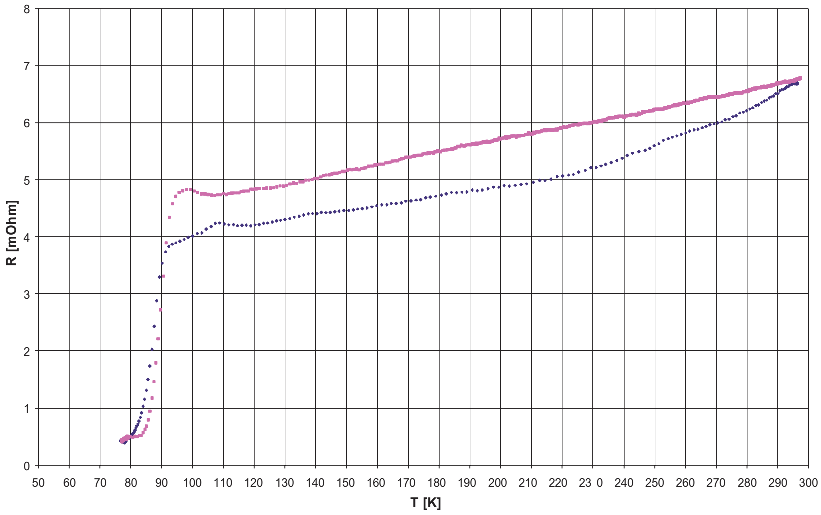

Fig. 8. – (Colour on-line) Free cooling down (blue) and warming up (pink) when magnetic field applied for sample 2.

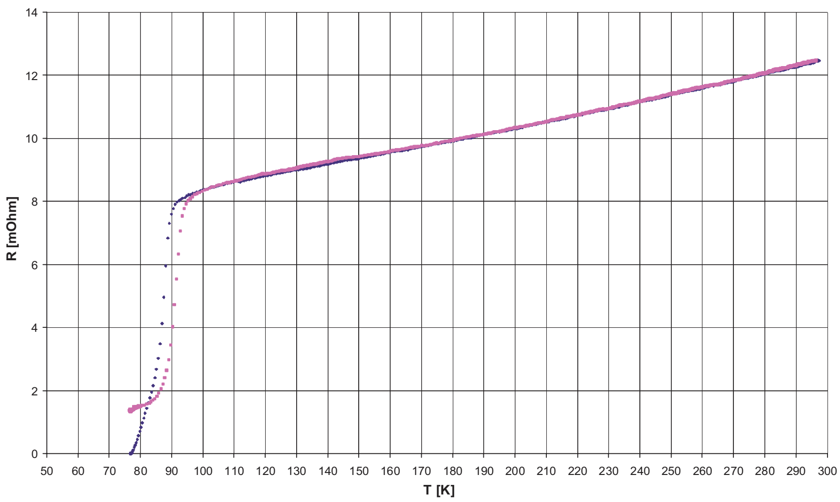

Fig. 9. – (Colour on-line) Free warming up with magnetic field (pink) and without (blue) for sample 1.

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