IL NUOVO CIMENTO Vol. 33 C, N. 3 Maggio-Giugno 2010
DOI 10.1393/ncc/i2010-10621-2

Colloquia: MPTL14

High-Tech Kit—The set of advanced activities from the MOSEM project

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(ricevuto il 30 Novembre 2009; pubblicato online il 23 Luglio 2010)

Summary. — One of the most tangible outcomes of the MOSEM (Minds-On experimental equipment kits in Superconductivity and ElectroMagnetism for the continuing vocational training of upper secondary school physics teachers—LLP-LdV-TOI-2007-NO/165.009) project is the set of advanced experiments—High-Tech Kit (HTK). The Kit contains the experiments, prototyped and tested among the project partners' schools and teacher training institutions. The activities are combined with e-modules comprising videos, animations, and modeling as well as with new support material for teachers and teacher seminars. The paper briefly shows some of the HTK materials as appropriate use of real and virtual multimedia in physics teaching and learning. The authors discuss the process of setting up same of the experiments and illustrate activities with the results of measurements obtained within.

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

1. – About the project

MOSEM—Minds-On experimental equipment kits in Superconductivity and ElectroMagnetism for the continuing vocational training of upper secondary school physics teachers is a multilateral project under Transfer of Innovation framework of Leonardo da Vinci Lifelong Learning Programme 2007-2013. A total of 27 partners are involved in the project. They are from 8 countries (Austria, Belgium, Czech Republic, France, Italy, Norway, Poland and UK) of which 10 universities, 10 upper secondary schools, 5 public valorization partners and 2 companies are responsible for developing, testing and disseminating project deliverables.

Fig. 1. – The inside view of HTK—both sides of the suitcase—all elements of the kit are assembled.

The main project deliverables are two kits (Low and High-Tech) with demonstrations linked with experimental materials and support materials (Kirstein 2007) such as videos, animations from the previous SUPERCOMET 2 project (Schorn 2006) and a teacher seminar with necessary printed teacher guides.

2. – High-Tech Kit

The prototyped High-Tech Kits are made as ready to transport suitcases and were delivered to partners for further elaboration and testing purposes during Ostrava workshop on 15 June this year (Greczyło 2009). Although not all parts of the sets were ready to distribute main elements together with HTK experimental booklet were handed out to partners and extensively tried out during the meeting. The tryouts were recorded and will be used to extract pictures and make different types of project movies (instruction, guide, illustrative). Figure 1 shows the inside view of the HTK suitcase.

The list of experiments which can be carried out with use of the HTK consists of the fallowing main topic items which consist of several activities:

4.1: Resistivity *versus* temperature

- 4.1.1 R *versus* T for metals
- 4.1.2 R *versus* T for superconductors
- 4.1.3 R *versus* T for semiconductors
- 4.1.4 What is the temperature of liquid nitrogen?

4.2: Persistence of current

- 4.2.1 Persistent current

4.3: Discovering levitation

- 4.3.1 Meissner levitation
- 4.3.2 Meissner and strong pinning superconductivity comparison
- 4.3.3 Testing the pinning
- 4.3.4 Inverted levitation
- 4.3.5 Feeling the pinning at different heights
- 4.3.6 Measuring the pinning at different heights
- 4.3.7 Meissner *versus* diamagnetic levitation
- 4.3.8 The tilted magnet
- 4.3.9 Try to do that

4.4: Let the train fly

- 4.4.1 First superconducting train experiment
- 4.4.2 Bad superconducting train
- 4.4.3 Good superconducting train
- 4.4.4 Make your own train
- 4.4.5 Pyrolytic graphite on tracks

4.5: Hall effect

- 4.5.1 Hall effect measurements for semiconductors

4.6: Gadolinium experiment

- 4.6.1 Gadolinium experiment

Experiments marked in black are provided with fully elaborated descriptions when those in blue are delivered with non-elaborated descriptions. Examples of such descriptions will be presented further in the text. The numbering system corresponds to the list of all project deliverables. The set was designed to allow performing a number of different experiments by a group of students at the same time - class.

3. – Examples of materials

To fulfill the needs of Teacher Seminar which is the main output of the project the materials were made in two different templates serving various requirements:

- Fully elaborated descriptions consisting of all parts necessary for successful performance of the tasks. This kind of documents presents main connections with other materials (movies, on line application) and gives compact explanations of physics essential to understand the experiment;

4.3 Discovering Levitation

4.3.1 The Meissner Effect

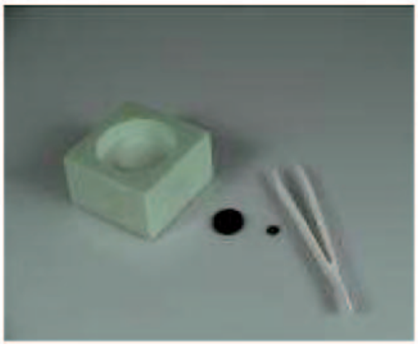
Student Worksheet

Safety Issues:

Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimised if the general safety precautions given at the start of this section are followed.

The second will not be a problem if you are working with one litre or less in an average sized laboratory. However if you have any doubts, or local rules, then please ask your local safety advisor.

Aim: to investigate the magnetic properties of a superconductor.



Apparatus: from the kit you will need

Meissner pellet; magnet; plastic tweezers; cup; liquid nitrogen.

Procedure:

Place the magnet on the pellet and investigate any magnetic effect:

1. What do you observe?

Put the Meissner pellet in the cup.

Put the magnet on the pellet.

Pour liquid nitrogen, gently, into the cup taking care not to wash the magnet off of the pellet. If this does happen use the tweezers to replace the magnet, never use your fingers.

Wait for the liquid nitrogen to stop boiling, the pellet is now at 77 K

2. What do you observe?

Let the pellet warm up to above its transition temperature.

3. What do you observe?

4. Can you explain your observations?

Levitation: The Meissner Effect Explanation Sheet

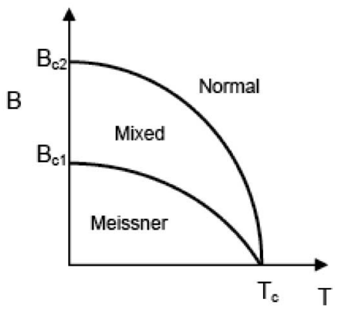
1. At room temperature the interaction between the magnet and the Meissner pellet is either very weak or none existent.

2. As the temperature is reduced by the liquid nitrogen, the magnet suddenly lifts up and levitates above the pellet. This is because below a critical temperature, T_c which is 92 K for the pellet in the kit, the pellet becomes superconductor and expels the magnetic field due to the magnet and this causes repulsion.

3. As the temperature of the pellet increases above the critical temperature it looses its superconducting properties and the magnet falls.

4. The Meissner pellet is a superconducting pellet with a low pinning ability. At room temperature, no strong magnetic properties can be detected; the magnet is neither repelled nor attracted to the pellet.

The order of the cooling procedure is important: the process used here is known as a field cooled experiment, the superconductor is cooled with a magnetic field, from the magnet, present in its bulk. An alternative cooling procedure, known as zero field cooled experiment, would be to cool the superconductor without a magnetic field and only after cooling, below the critical temperature, is the magnetic field introduced by bringing the magnet near. With the pellet used in this investigation both procedures would give the same end result but only the field cooled experiment demonstrates the expulsion of flux or the Meissner effect.



Superconductivity cannot exist in the presence of a magnetic field, so the superconductor repels the magnetic field from its bulk. In doing so, it creates a force that repeals the magnet, hence the levitation. The polarity of the magnet plays no role: the magnet can levitate both sides.

Since a superconductor can sustain a current without dissipation, a current flows around the border of the pellet and this creates a magnetic field which opposes the field of the magnet. The net field is therefore zero in the bulk of the superconductor. This current creates a force on the magnet causing the levitation. Hence the levitation height is a compromise between the weight of the magnet and the force created by the superconducting currents within the bulk to screen the magnetic field.

However if the magnetic field is too strong the superconductor will not be able to screen it and above this critical field superconductivity cannot exist, just as it cannot exist above a critical temperature.

This effect shows that a superconductor is not just a material with zero resistivity, it is more than that. A metal with zero resistivity would not repel the magnetic field since there is no incompatibility between magnetic field and a perfectly conducting metal. However a perfect metal would be incompatible with a change of magnetic flux, remember Lenz's Law, since a perfect metal can not sustain a difference of potential: a perfect metal would trap the magnetic field of the magnet with permanent eddy currents but not repel it.

The reason a superconductor cannot coexist with a magnetic field is directly rooted to the nature of superconductivity: the wave nature of the Cooper pairs has its phase altered by the magnetic field. This effect is thus a direct manifestation of the quantum nature of superconductivity.

The Meissner effect is the main source of the levitation displayed here, but were it the only one, the levitation should not be stable. The expulsion of the flux should have expelled the magnet, which it does, but the magnet would be pushed to the side and fall. The fact that the magnet remains over the superconductor when it is pushed with the tweezers shows that there is a "link" between the two, link which is rather weak in this case, but present nevertheless. Actually, there are two types of superconductors: type I, that behaves as explained above, and type II, that have a behaviour which is rather more complex, responsible for the existence of the "link". The superconductor used here is a type II.

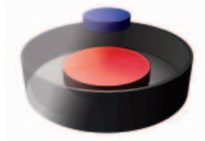
Additional Experiment

A simple experiment can be used to demonstrate that a pure Meissner effect should allow for levitation. A pure Meissner effect, type I superconductor, or a type II superconductor below Bc1, will behave as a perfect diamagnetic material.

The question is, can a magnet levitate above a diamagnetic material?

Let the students try such a levitation with the magnet and a wafer of pyrolitic graphite. Since the diamagnetism of the graphite is far from perfect, even though it is one of the highest known in material which is not a superconductor, the weight of the magnet will be too high. If the investigation is inverted the physics is exactly the same, let the students try to levitate the graphite over the magnet. The graphite will glide and fall. This demonstrates that diamagnetism alone can not be the explanation for the levitation of the magnet over the superconductor.

– Non-elaborated descriptions which describe concepts of the activity and giving the readers only main information related to the experiment. This kind of materials shows directions of possible HTK elements' uses—to be explored by teachers.

Number of experiment **4.1.4**	*Title of experiment* What is the temperature of Liquid Nitrogen? (using a platinum thermometer)	
Picture of setup	*Necessary equipment* Half a litre of liquid nitrogen; Liquid nitrogen container; platinum resistor; wires and plugs (non in the kit); Soldering iron (non in the kit); Calibration table for Pt100; Ohmmeter.	*Chapter/where it fits (part of learning line)* The dependance of temperature of the resistance of the Pt100 can be linked to experience 4.1, resistivity of a metal.
How to setup this experiment? How to get ready for it? First the wires and plugs should be soldered to the Pt100 as depicted above. That way the resistance of the platinum can be read with the ohmmeter. Depending on the age of the students, the teacher may consider doing it himself before hand. Pour liquid nitrogen in the container.	*The physics of the experiment* The Pt100 is a classical thermometer, measuring its resistance is a standard way of measuring temperature. At 0 °C, the resistance of this standard is 100 ohms. Below 30–40 K its resistance does not vary a lot with temperature, making it a bad thermometer in that region. The site www.lakeshore.com proposes different thermometers depending on the temperature range, and gives technical specifications.	*Pedagogy* Before doing anything, ask the question "how can we measure the temperature of liquid nitrogen", and let the students think of what a thermometer can be. Let the students first realise that the resistance of the Pt100 changes with temperature by warming it up with your hand, or using a small hairdryer. Then give them the table, and check room temperature.
Set of Minds On questions Why is the nitrogen boiling? Does the temperature of liquid nitrogen depend on the temperature of the room? Does the temperature of liquid nitrogen depend on the weather? Is the Pt100 a good thermometer below 30 K? Why is the Pt100 called Pt100?	Liquid nitrogen is boiling, which means that the heat it receives from the warm room is used to transform liquid into gas. This is a first order transition, which means that it happens at a given temperature, as for any liquid. For water, under ambient pressure, it happens at 100 °C. For nitrogen, it happens at 77 K, so this is the temperature of the liquid (as an analogy, imagine a pan of water in a hot oven: comparatively to the temperature of the oven, the boiling water is cool!). Nitrogen gas is 80% of the air we are breathing, it is a transparent non toxic gas (good news).	

	The atmospheric pressure will have an effect on the temperature of the boiling nitrogen, in the same manner that the atmospheric pressure will change the temperature of boiling water.	
(How to) start the experiment? *Observations* Check the value of the Pt100 resistance at room temperature. Dip the Pt100 in liquid nitrogen. What are your observations? What is the temperature of liquid nitrogen?	*Hints* The white fumes are not nitrogen (it is transparent, 80% of atmosphere is nitrogen), but it is water moisture from the atmosphere condensating in the cold vapours of nitrogen gas. The droplets of liquid nitrogen run without friction on the table because of a cushion of nitrogen gas below the droplet. A similar effect happens when a water drop falls on a hot plate.	*Link to other files (online module, media database, ...)*
(Warnings!!) = Safety issues Soldering iron; Liquid nitrogen.		

4. – Examples of data

High quality elements of the Kit allow obtaining valuable experimental data. We present here results of same measurements performed for the experiment 4.1.2 in which it is possible to carry out exploration of resistivity *versus* temperature for superconductors. Figure 2 shows the results registered for two superconducting cylindrical sample of diameter $d = (20 \pm 1)$ mm baked from YBaCuO powder purchased at Aldrich which were warmed up freely from liquid nitrogen temperature up to room temperature (Greczyło 2009).

5. – Conclusions

The primary target group of the project is teachers of science in upper secondary schools and trainee science teachers at universities. It is also expected that teacher training departments at universities will implement the teacher seminars and new materials developed. Therefore there is high chance that use of the MOSEM kits will possibly contribute to formal/informal development of physics curricula. In project participants' opinion MOSEM outcomes will help to overcome the crisis in physics and science education in Europe by promoting lifelong learning in physics and pedagogy for science teachers at the upper secondary level especially by assisting them with appropriate use of real and virtual multimedia. Supporting them in physics teaching and learning processes by well organized and structured materials will possibly help to overcome a lack of

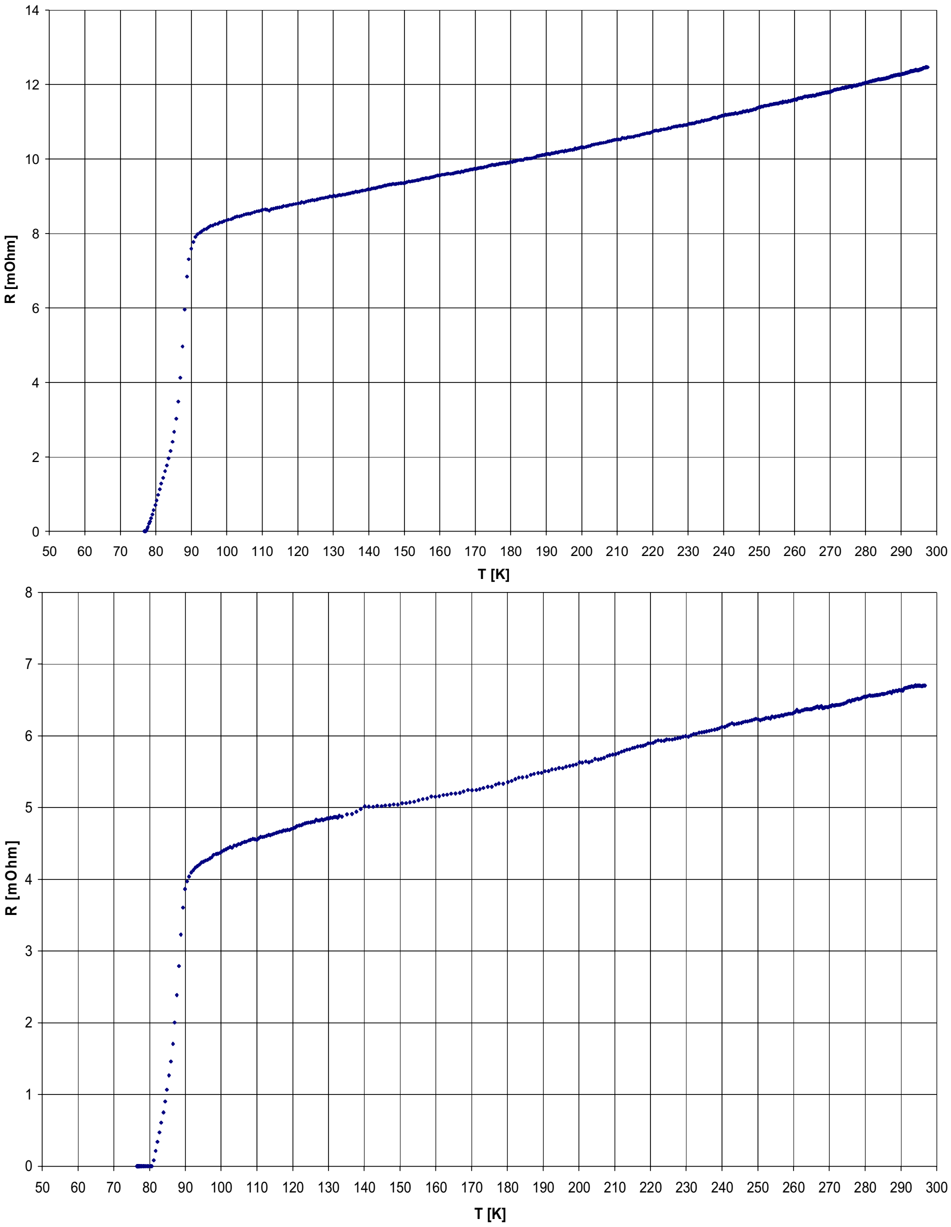


Fig. 2. – Curves showing resistivity *versus* temperature obtained with HTK.

competency. Such science teachers are able to provide for breaking negative associations with the subject of physics (Smithers 2008).

Good examples of interesting experiments with associated materials presented in the paper developed in the framework of MOSEM project are a step to establish the goal.

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