MOSEM Teacher Guide

Minds-On experiments in Superconductivity and ElectroMagnetism

A Leonardo project for continuing vocational training of upper secondary school physics teachers

SRD

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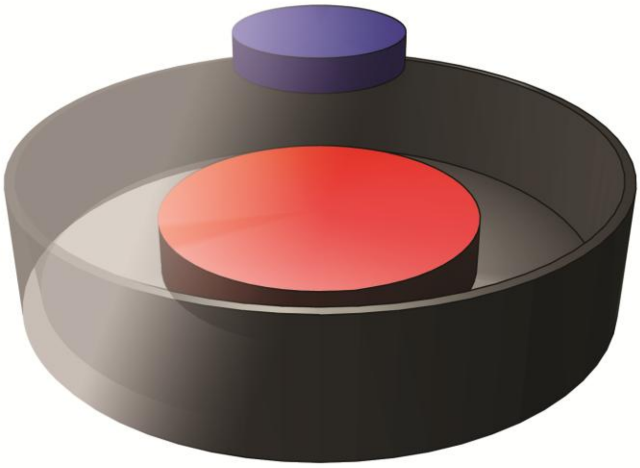

MOSEM: Minds-on experimental equipment kits in Superconductivity and ElectroMagnetism for the continuing vocational training of upper secondary school physics teachers

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Introduction

The MOSEM project aims to improve the competency of physics teachers across Europe by promoting a “Minds-on” approach to learning physics, activating not only the learners’ hands but also their minds.

Schools, teachers and students are offered a concept of simple physics experiments blended with electronic and printed support materials including videos, animations, photos, illustrations and structured text detailing the scientific, practical and pedagogical issues.

Our aim is to inspire learners and motivate them to explore the world of physics, and also to promote equal opportunities in learning physics.

Does it work?

Evaluation of the developed materials show that both female and male students are equally positive – very positive – to the Minds-on format and the level of difficulty for both physics content and practical setup of experiments.

Teachers with and without a physics degree were equally represented among those participating in our teacher seminars during the project. Both groups were positive to the structure and contents of the seminar, and also positive to the materials and their effect on students.

Both the participating students and teachers were generally motivated above average for physics before doing our experiments, but our reports indicated that students who usually were silent and less responsive in class were much more active during our trials. These students also reported a high degree of satisfaction with this format of learning.

One student commented that learning with these experiments was “interesting and challenging”, which captures the essence of our “Minds-on” approach.

What did we do?

We developed and tested a teacher seminar promoting an active learning philosophy. The seminar gives first-hand experience with different methods for facilitating conceptual learning. A collection of simple, thought-provoking tabletop experiments for learning and teaching central concepts of electromagnetism and superconductivity was specially developed for this purpose.

Teachers can combine the physical setup of the learning arena and the choice of activities and resources to emphasize different learning goals. The activities are intended to raise the curiosity of and motivate the learners to investigate the encountered phenomenon more closely.

The most tangible outcomes of the MOSEM project are two sets of experimental kits containing the aforementioned experiments, prototyped and trialled among the participating schools and teacher training institutions.

One set contains experiments using superconductors. It requires a supply of liquid nitrogen and is called “High-Tech”. The other set relates to the basic experiments in electromagnetism and is called “Low-Tech”. Students can do their own research with the materials provided, within a frame for guided, open-ended learning.

Printed and electronic support materials (including this teacher guide) are designed to meet the curiosity of learners across Europe as they explore our pedagogically designed experiments. Investigating an encountered phenomenon with the provided materials and other sources is intended to improve motivation and learning.

The MOSEM project builds on the SUPERCOMET 2 project which developed the first version of the electronic learning modules and conceived the concepts for the Minds-on experiments. A twin project, MOSEM^2, develops quantitative materials complementing the conceptual materials developed in SUPERCOMET 2 and in MOSEM (Minds-on experiments).

Why did we do it?

Europe lacks competent physics teachers – driving a negative feedback loop that hinders recruitment of good candidates who can turn the trend. This situation is ongoing at both national and European levels, as has been documented by several studies and conferences in recent years[1].

The MOSEM project contributes to improving this situation by promoting lifelong learning in physics and pedagogy for science teachers at the upper secondary level through offering a range of Minds-on experimental kits based on existing commercial and non-profit solutions, as well as the outcomes of previous related Leonardo projects.

Who are we?

The partnership includes leading European physics educators with a proven track record of collaboration in previous projects, as well as being frequent contributors at international conferences for physics education. As valorisation partners, the consortium includes a number of large professional organisations for teachers and engineers that have been active in the public debate on science education. Upper secondary schools in established partnerships with the teacher training organizations and universities behind the project proposal participate as testing schools for the developed products.

Are you Minds-on?

After three years of hard work the MOSEM project has come to an end. But the fun part begins now! Using these materials to implement the Minds-on philosophy in teacher training and physics education has been our motivation, and now we long to see it happen. But it doesn’t happen by itself. Dear reader, it is up to you.

[1] Smithers, A. and Robinson, P. (2008). Physics in Schools IV: Supply and Retention of Teachers. Carmichael Press, Buckingham, UK

Products

The MOSEM project developed a range of teaching and learning materials.

Learning materials

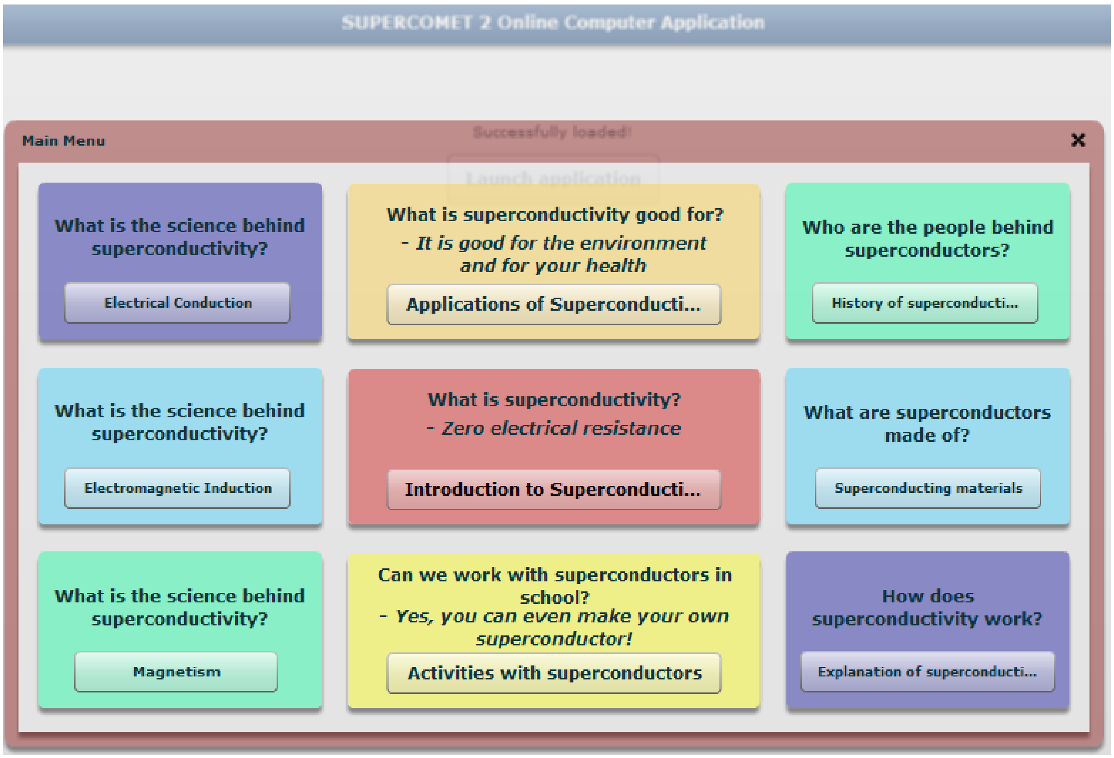
Experimental kits

The experimental High-Tech and Low-Tech Kits each contain a large collection of equipment and materials for performing a number of experiments. Both materials and experiments are described in details further in the guide.

Online modules

Developed by the SUPERCOMET and SUPERCOMET 2 projects, the online learning modules contain computer animations providing a different view of the experiments, displaying invisible electric and magnetic fields, allowing students to repeat experiments in slow motion, avoiding practical problems with setup, etc. They are useful for repetition of or preparation for real experiments, but should not be used instead of such experiments. The adress is online.supercomet.eu.

The main menu of the SUPERCOMET Online Learning Modules is shown below. 3 modules relate to electromagnetism and 6 modules deal with superconductivity.



Videos

Videos of the experiments augment the animations, help memory and also provide guidance on how to perform experiments. However, as with the animations, videos should not be used as a surrogate for real experiments. Several of the videos are available at youtube.mosem.eu.

Support materials

The Teacher Seminar is supported by a framework for blended learning with the experimental kits and other learning materials. The support materials provide and describe this framework.

Teacher Guide

The MOSEM Teacher Guide is intended to outline the pedagogical rationale for using the project outcomes. It suggests effective ways of using all or parts of the MOSEM products (experimental kits, multimedia tools, learning methods) in the classroom as part of everyday teaching.

It contains detailed activity descriptions for the High-Tech and Low-Tech Kits. Different sections cover the Minds-on approach to learning and teaching, the teacher seminar, the descriptions of the actual Minds-on activities and the results of the evaluation. Furthermore, the teacher guide contains some basic information about the physics of superconductivity, and it shows possibilities for evaluating the work.

Teacher Seminar

A number of electronic files with presentations, worksheets and documents for structuring the teacher seminar are available for the teacher trainer giving the seminar.

Media database

The project created a Moodle database for sharing photos, videos and documents relating to the experiments described in the Teacher Guide. This database functions as a repository for all media files produced in the project, and ensure that they can be used in various electronic and printed support materials.

Online discussion forum

Teachers registered in the project forum (forum.mosem.eu) at the teacher seminars, in order to exchange ideas and results online. An online community of teachers can communicate and cooperate on Minds-on teaching and learning activities between schools and even across borders. Just follow the instructions to register.

Minds-on Learning and Teaching

Introduction

The MOSEM project promotes discovery learning allowing students to play an active role in their learning. Students are involved in activities and exposed to several different teaching approaches. When students are performing experiments themselves it is usually called a hands-on involvement, but when the teacher is involved and challenge students' understanding of the phenomena (experiment, activity) it is recognized as a Minds-on approach.

In the teacher guide we wish not to tell teachers how to use experimental kits during their lectures, but we provide a variety of different learning and support materials for educators that they can adapt to their teaching needs and approach. The project also adds a European dimension by developing materials which can be used in different national curricula.

The following formats for carrying out the MOSEM experiments illustrate the core ideas of our Minds-on approach. The highlighted steps are crucial and therefore need special attention by teachers.

Format 1 – Confront predictions

1. Set up experiment according to description
2. **Do not start the experiment nor do any experimental observations**
3. **Students predict what will happen** (phenomenon, numbers, behavior), preferably written (short keywords)
4. Perform the experiment
5. Students observe what is happening, let them speak out loud, or write it down (make sure everybody participates)
6. **Confront students' predictions with observations** (self or peer evaluation)
7. Go to theoretical background (conceptual or in dept and numerical)
8. **Look for thinking errors**
9. Students discuss practical applications of this physical phenomenon
10. **Students reflect on the learning activities and learning process**

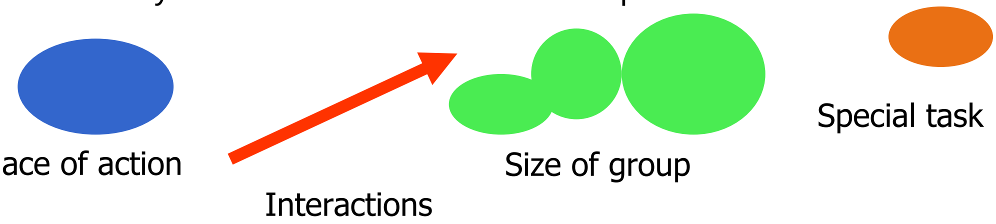
Format 2 – Confront explanations

1. Set up experiment according to description
2. Perform the experiment
3. Students observe what is happening, let them speak out loud, or write it down (make sure everybody participates)
4. **Do not give any theory, solutions or explanations**
5. **Students discuss/write down the physics behind the experiment** (partially, what phenomenon, laws, processes, formulae are optional)
6. Go through theoretical background (conceptual and/or numerical)
7. **Confront students' explanations with the real theory** (self or peer evaluation)
8. **Look for thinking errors**
9. Discuss practical applications of this physical phenomenon
10. **Students reflect on the learning activities and learning process**

Teaching methods

Here we present examples of different ways to organize the learning activities. The methods presented here are especially useful for the Minds-on approach and are based on project participants' experience and inspiration coming from ©Steunpunt Intercultureel Onderwijs and ©2006 Stichting leerplanontwikkeling (SLO), Enschede, author: J.H. Flokstra.

We use these symbols to illustrate the main components of the methods:



Construction of knowledge

The method bases on a group work. Each group should be maximum 4 students. Every group gets complementary information. All people from a group are studying different small experiments (aspects). After that they come together and combine each others' knowledge/experiences to a coherent theory.

Aim: Students are forced to work together because they all have different information.

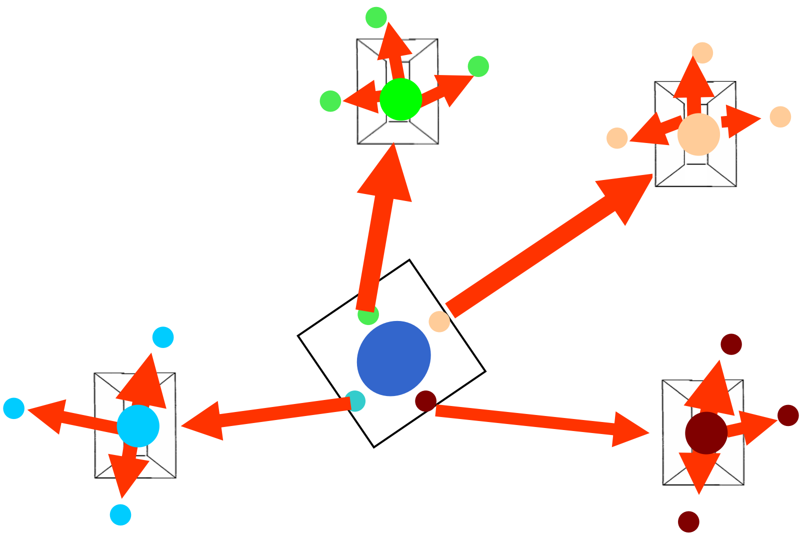
When to use it: For different applications of a subject, but also for theory.

Time: Preferably 30 minutes.

How: Typical sequence of experiments/exercises/applications.

<u>Step 1:</u> The material must be divided logically in several more or less equal parts. Each part can also be treated independently from each other. Each group gets one part.

<u>Step 2:</u> Each student studies his part. If necessary the teacher can add supporting questions and tasks.



<u>Step 3:</u> Exchange within the group: students bring in their work and assemble everything in one coherent unit.

<u>Step 4:</u> The teacher tests whether all students have understood everything.

Travel – first variation

Each group get a different task. They carry out this task and discuss the results

Goal: Exchange of information and knowledge, evaluate each others' opinions, use of exact language, terminology etc.

When to use it: Start of a series of lessons, when an important issue is coming up, to stress a certain point of view,

Time: Fraction of the lesson period

Preparation: Small experiments, video clips, etc.

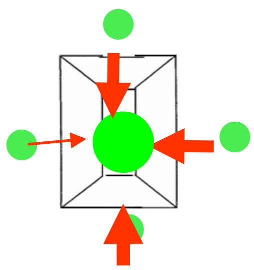
Subjects: Series of experiments, series of problems, mixed offer: experiments, articles, applications on the same subject.

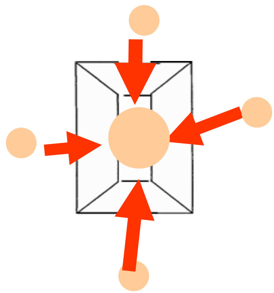
How:

Step 1: The teacher forms groups of 3 or 4 students and gives them all a task

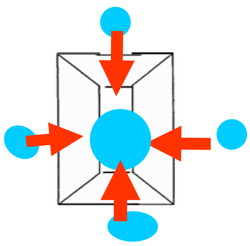
Step 2: The group discusses the answer and every member writes this down in short.

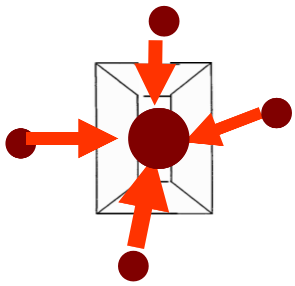
Step 3: One member of the group remains seated, the others move one, two or three groups further.





Step 4: In these newly formed groups all members explain each problem to the others. There is a short discussion and some tile to ask additional clarifying questions.

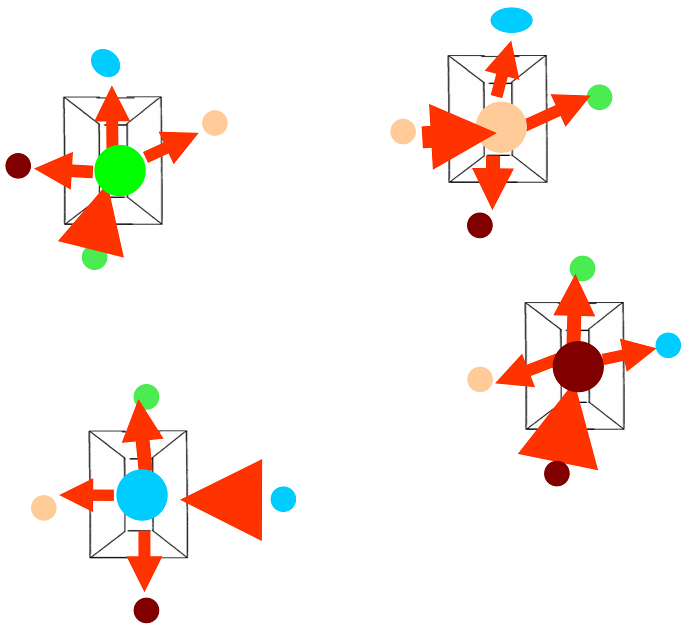




Step 5: The students return to their original groups and report on their travel experiences.

Travel – second variation

This method is variation of the previous one. Members of the groups move 1, 2 or 3 places.



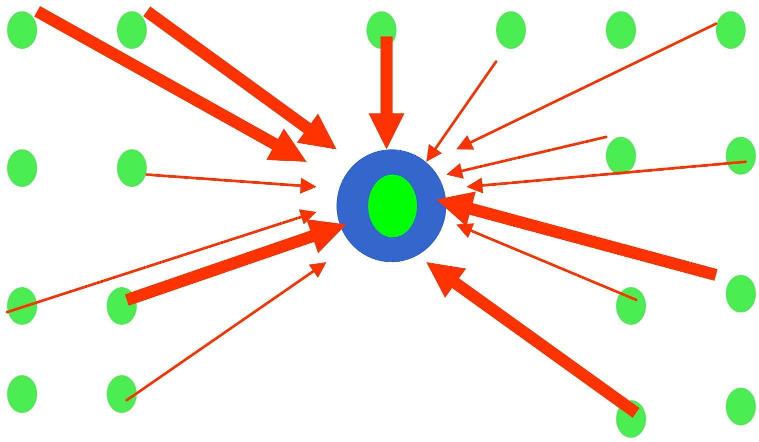
All group members get to know the problems the group is confronted with.

The members then go back to their original groups.

Bingo

The method is valuable for launching a lot of different kind of information, ideas, graphs, words, pictures, etc.. Every participant has a different scheme and indicates on a paper what is announced.

Aim: Rehearsal of items, exact use of terms, general knowledge



When to use it: When starting a subject to activate previous knowledge, at the end of a chapter, as a rehearsal, to drill certain skills, as an introduction for a workshop.

How: Every student has a table with all kinds of items in the different cells. All tables are different, but contain the same cells. One student reads ad random the content of different cells. He indicates the cells he read. The other students listen and put crosses in the cell which, in his opinion, is read. The first to have a full row of crosses in his table, wins.

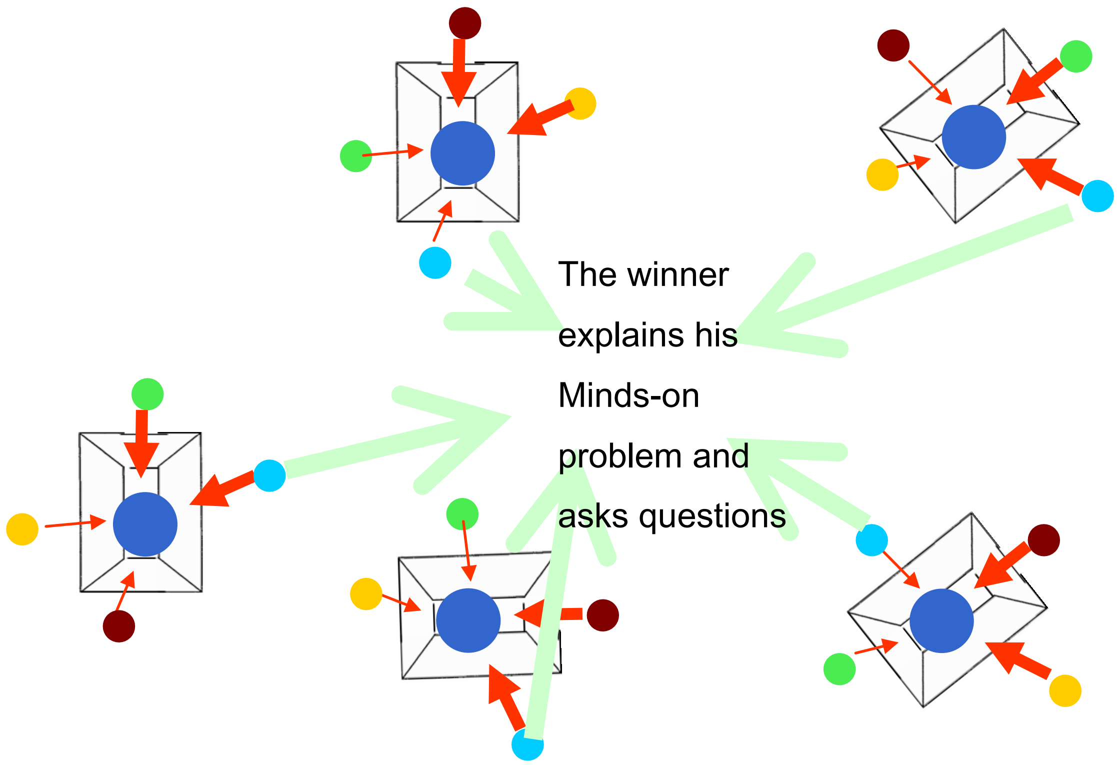
Advantage: All students listen/participate; element of competition; chances to stress things or to indicate how important some things are.

Preparation: This is a lot of work, time consuming.

Lotto

The method emphasizes Minds-on problem approach for a group work. Normal problem solving with one winner who explains the problem and ask questions.

Goal:	Improve collaboration and solidarity in a class.
When to use it:	Do this several times a year, to spread equal opportunities.
Time:	Part of a lesson.
Subjects:	Video with “strange” phenomenon, numerical problems, small experiments.



How: <u>Step 1:</u> Instruction: the teacher gives each group of 4/5 students a Minds-on task (experiment, problem, graph, video, etc.). Each student in the group has a different number (colour).

<u>Step 2:</u> The group solves the problem as good as possible, and writes down questions on items that need clarification. Each member needs to have individual notes.

<u>Step 3:</u> The winning group/and colour (= 1 student) is announced. This person explains to the class the problem, what the group has solved so far and (if necessary) additional questions. The rest of the class helps to solve remaining problems.

<u>Step 4:</u> Reflection by the teacher: were the initial ideas ok? Were the questions well formulated? Did the winner lead the discussion well? On evaluation: the central person needs to get good marks, but all of the others need to help. All students with equal numbers, coming from different groups, could meet to exchange their Minds-on problem shortly.

Lab experts

The method also bases on a group work. Groups of 4 "specialists" study experiment/task. Newly formed groups synthesize their knowledge.

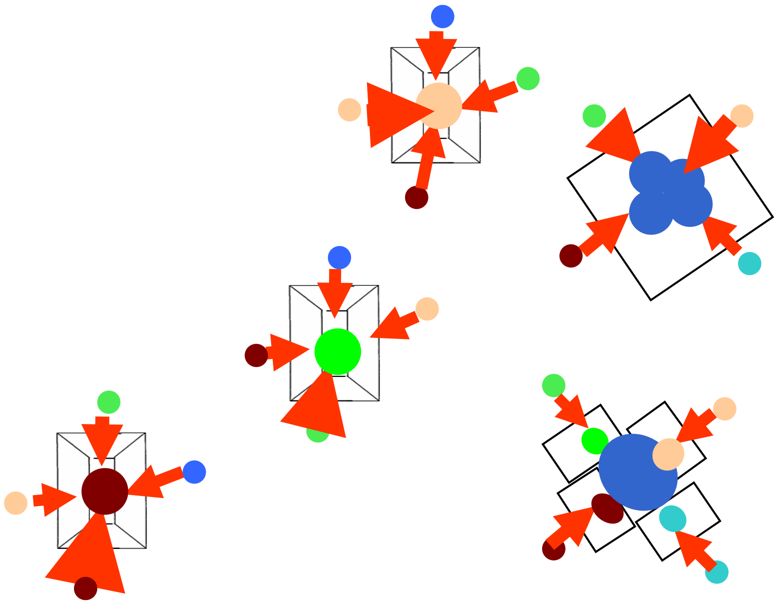
Aim: Students become experts each in one (small/part of) experiment. They have to transfer this to their fellow students.

Time: Around 1hour.

How:

Step 1: formation of an "initial" group

Groups of 4 students are formed. Each gets a colour or a number (1-4, if there are 4 experiments). All students with the same colour/number go to their specific experiment, in which they get "experts" (building, analysing, performing, data, graphs, conclusions) by working together in this group. The depth of this activity can vary (time-goals), depending on the teachers' vision. The means the students get can vary from self-sustaining up to a guide including all explanations. The way they prepare for the transfer of their knowledge to the group can be determined by the teacher, or the group can decide.



Step 2: the group of experts split back to the "initial" groups. These group now starts to rotate from one experiment to another, and each time the specific expert leads the learning process.

Step 3: All experts put together the information they got and this becomes a small course. The group then formulates final conclusions, based on the whole of the information. To keep an eye on the quality of the information, one can send two experts per basic group to each experiment. In an intermediate phase the teacher could check what each expert group has found/ one can also use a key with good answers /one could use a tutorial.

Subjects: Series of different subject experiments or series of small experiments on the same subject (electrostatics, dynamics, heat, particle model, relationship resistance-temperature, induction, optics).

Hint: This is also useful if one organises a basic group for different aspects of a certain subject such as: starter, basic experiment + data gathering, formula, problems, application(s).

More about the Minds-on approach

For some considerable time there has been a general acceptance that students come to science classes with firmly held beliefs about the world around, to be ignored by teachers at their peril. Sometimes these beliefs have been variously described as misconceptions, prior conceptions, preconceptions, pre-instructional beliefs, alternative frameworks, naïve theories, intuitive ideas, untutored beliefs, misunderstandings, naïve ideas, misconceptions or alternative frameworks.

For the sake of clarity, the authors would seek to use the term alternative conceptions in the sense of sets of ideas that, in the mind of the student, can be seen as a meaningful and logical alternative to those held by the scientific community.

Although not exclusively[2] so many studies focusing upon children's alternative conceptions were carried out from the 1970s onwards[3]. Many studies[4] tended to concentrate upon children's mastery (or not) of concepts from the world of physics. Alternative conceptions have also been commonly reported in other branches of science[5].

However tempting it may be, alternative conceptions are not matters of concern exclusively for those teaching younger or less able students to address since researchers have also reported problems amongst university students[6] and within different cultures[7].

As noted above, there have been numerous studies that have dealt with issues relating to commonly held alternative conceptions amongst our students. However, in an examination of published literature on alternative conceptions, out of the 365 studies reported within an 11 year period, Goodwin (1995) found 5 that related to those existing within teachers themselves.

Such findings have been replicated in subsequent studies focusing upon student teachers' concept mastery[8]. Although, as is the case with children and, in agreement with an earlier study by Clement (1982), Palmer (1997) found that, even after instruction, significant proportions of student teachers held on to their alternative conceptions, he did find that the more mature a student is, the more consistent he or she is likely to be in the application of an accepted idea.

As to the sources of these alternative conceptions, King (2000) attributes partial responsibility to a combination of lack of teaching, errors in printed texts, syllabuses and examination questions and occasionally to anomalies within the science itself. Alternatively, Elaine Reynoso (1993) cites inaccurate reporting in

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[2] for example, see Hancock, 1940
[3] for representative reviews of such research see Driver and Easley, 1978; Driver and Erickson, 1983; Duit, 1987; McDermott, 1984
[4] such as those of Bar et al. (1994) and Brown (1994)
[5] for examples within the field of chemistry, see Schmidt, 1997 and Taber, 1996
[6] Kaiser et al., 1986; Elaine Reynoso et al., 1993
[7] Bogdanov and Viiri, 1999; Van Hise, 1988
[8] Willson and Williams, 1996; Schoon and Boone, 1998

the mass media while Willson and Williams (1996) are of the opinion that prior learning amongst biologists may sometimes inadvertently contribute to subsequent confusion when learning outside their own specialism.

On the other hand, Goodwin (1995) is of the opinion that examination systems themselves may contribute to a vicious circle of misunderstanding, arguing that students may sometimes have been able to pass an examination by rote learning seemingly meaningless material and regurgitating this, coupled with specialised terminology, at a more or less appropriate moment.

The latter problem may be compounded if the students' teacher had employed such an approach in order to gain his or her own qualifications. In addition to the possibility of any such rote learning without understanding being rewarded by examination success, Elaine Reynoso further argues that the evaluation process itself is likely to direct the students' learning, in that, in their quest for success, students not unexpectedly focus upon what material is likely to be tested.

If there are significant problems with our trainee, or practising, teachers' concept mastery, the question arises of how detrimental to their own teaching is this likely to be? Barnett and Hodson (2001) argue that having adequate subject knowledge is essential to give teachers a sense of personal control and provide them with a secure social location as a teacher.

In agreement with this view, Stevens and Wenner (1996) report that teachers gravitate towards performing those tasks in which they feel confident and competent although their research does highlight the tendency for trainee teachers to err on the side of optimism when considering their own abilities.

However, when in a position of insecurity with respect to their own understanding, Ameh's opinion (1987) is that this may not be quite as detrimental as one might expect since teachers in such positions are likely to rely more heavily upon the authority of resources such as printed text. A caveat should accompany this approach though since, as is common with the majority of school texts, those drawn upon are likely to present concepts as statements of fact and not address, or even raise, the possibility alternative conceptions commonly held by students.

CASE approach

It is not uncommon to find elements of the Cognitive Acceleration through Science Education [CASE] program of teaching in a significant number of science departments of secondary schools in the UK and Europe[9]. As an illustration, at a conservative estimate, around 4500 science teachers are likely to have had some exposure to training in the CASE approach since its inception in 1991.

Cognitive Acceleration through Science Education is an approach to science teaching designed by Philip Adey, Michael Shayer and Carolyn Yates (1995) with the intention of raising children's intellectual performance. The theoretical basis behind CASE is a combination of the ideas of Piaget and Vygotsky and involves

[9] Adey, P.S., Shayer, M. & Yates, C.(1989). Thinking Science: Student and Teachers' materials for the CASE intervention. London: Macmillan

32 ‘Thinking Science’ lessons which are designed to be delivered, at regular intervals, over a two year period to children in Years 7 and 8 (ages 11 – 13 in the UK).

At the end of a two year trial period, students who had experienced the ‘Thinking Science’ activities showed greater gains in cognitive development than matched control groups. When, in due course, at the age of 16, the trial group completed their GCSE (General Certificate of Secondary Education – a public examination taken by the majority of students in England and Wales) examinations in Year 11, they performed significantly better than the control group, not only in science but also in mathematics and English[10].

When further teachers had been trained in the process and the exercise was repeated, results showed that schools who adopted CASE methods obtained between 14 and 25% higher grades in science, mathematics and English than non-CASE schools[11].

A typical CASE lesson has five components, namely:

1. Give the students a concrete experience that has a regular/predictable pattern.
2. Arrange for an unexpected result that does not agree with the previous pattern (cognitive conflict).
3. Have the students consider and share their old/new ideas with each other (metacognition).
4. Students construct their new reasoning process.
5. Reasoning patterns developed in CASE are bridged to other contexts.

The activities described in this text are based on, but not exclusively, the CASE approach. We are expecting the learner to ‘actively think’ rather than simple ‘actively do’ making our approach more than hands-on or to use the CASE terminology we would see our approach as meta-hands-on. This we will call Minds-on science teaching.

For example the falling magnets investigation gives students:
1. data that appears to have a regular pattern;
2. an expected result when they compare observation and prediction;
3. an opportunity to discuss their ideas;
4. an opportunity to develop new ideas;
5. an opportunity to make the bridge to other contexts - addressing the wider issue of making predictions in science with limited data.

[10] Adey and Shayer, 1994; Shayer, 2000
[11] Shayer, 1996

Teacher Seminar

Support materials for the Teacher Seminar

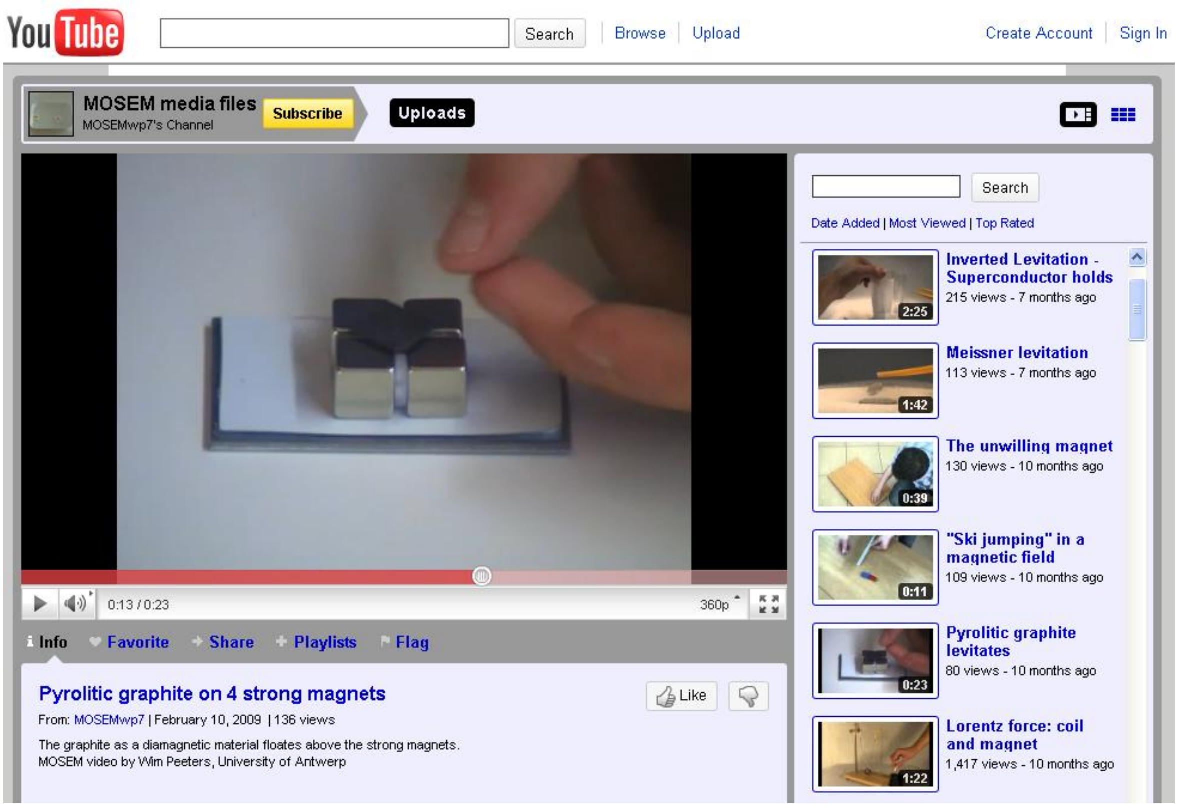
Support materials are organized in electronic folders available at mosem.eu. The folder "MOSEM for teacher trainers" contains schemes, background documents and information that the trainer should read/know before giving the seminars.

The folders Session1 to Session4 contain documents that need to be used during the session and can be copied or put to the disposal of the participating teachers – these documents are marked in blue when listed in the timetables for each session on the following pages.

All sessions rely heavily on materials brought together by the whole partnership, they can be found in various digital resources:
MOSEM_WP5_DigitalGuide Of DigitalMeans.xls

YouTube channel

An important resource is our YouTube channel (youtube.mosem.eu) where we have uploaded videos of many experiments. In connection with the discussion forum (forum.mosem.eu) we envision using YouTube for sharing videos among teachers and students as they perform the Minds-on experiments.



Teaching with MOSEM materials

Within the MOSEM project we advocate the attendance at a teacher seminar prior to using low and High-Tech experimental kits linked with on-line animations. The seminar will address both subject knowledge and alternative conceptions and in addition offer pedagogic approaches to the material to be covered. All of this takes place in a supportive environment with an emphasis on developing both the participants and presenter.

A teacher seminar does not only transfer knowledge to teachers, but can aim at different goals, at different levels of teachers' professionalism. Also serves as a platform for a network of active learners.

Experiential/Activity level

In SUPERCOMET 2 the teacher seminar was very content oriented, and the additional value was that new kinds of teaching methods were used. These were ready for classroom use. According to M. Michelini this kind of teacher training is called "experiential": this means that the teachers are considered as learners very much like students are considered in a class room. Sometimes they are considered as teacher-colleagues too, when discussions are taking place.

For MOSEM the first type of teacher seminar is analogous. It consists of a large number of files, in which every step is described in detail. The teacher trainer, and the group of teachers follow these guidelines rather strict (apart from local adaptations). Basically intellectually, the teacher remains passive in the sense that he absorbs ideas.

The teacher enhances his knowledge and some skills, but not his attitude towards learning. Although an evaluation is done at the spot, there is no guarantee that the teachers will implement the materials in the class room.

Action research can reveal this and can be used as a follow up strategy to "motivate" teachers to use the materials. However, success on the long term is questionable. In Flanders this is called the "activity" level of teacher trainings. Most training sessions have this character.

Metacultural level

On a "higher" level of teacher formation, another kind of teacher seminar will be put together too: the "metacultural" one. This is less extensive in preparation, and is a learning style based on equality between all participants, the teacher trainer included. Crucial for this method is interaction and discussion, along with good preparations by both - the participants and the teacher trainers.

Teachers discuss with the responsible of the educational proposal:

a. Guidelines of the proposal
b. Learning paths suggested
c. Educational materials
d. Experiments.

The responsibility of the implementation and of the way to do (approach, activities, teaching style, learning materials for students, assessment and evaluation, etc.) will be left to the individual participating teacher.

Apart from the content of the discussions, there is some strategy necessary to order and organise the discussions in a way that all participants are active, and that all learn. Also, some reflection is needed in this format.

Process and Development levels

In Flanders this metacultural approach is divided in two, which we call “process” level and “development” level of teacher trainings.

The process level aims at reflection by the teacher on how to do things in the class room (in this case: how can I implement the MOSEM materials), what is necessary to make this a success, and to find a solution to his questions and problems with the active help of the trainer and the group.

He is trying and willing to become a learner, but is still working on that and needs help from equally regarded colleagues. On the long term implementation depends on external factors: how do the students react, does everything work as planned, is there enough time. In some cases, teachers might give up implementation.

In the development level the teacher already has competencies on all levels: knowhow, skills and attitudes to tackle new challenges. The group discussions and the materials presented are regarded as an opportunity to improve his competencies. The teacher is already a learner, and will implement at least the usable materials, no matter what happens.

Situated/Manager level

The third kind is the “situated”. Workshop discussion of materials (1 style) is very short. Teachers read materials offered (cards for experiments and for multimedia materials) and decide the learning project to implement in classroom.

In a second Teacher Seminar they present the proposals and discuss with colleagues. Then each cluster of teachers experimenting will meet and discuss with the responsible, partly via web and partly in meetings. Results will be compared step by step and teachers modify step by step their activity.

In Flanders this is called the “manager” level of teacher trainings. The teachers are capable of integrating (collect, evaluate, adapt and implement) all new materials themselves. Teacher trainers might not be necessary for the content, but they are needed as organisers of meetings and as peer reviewers of the work done.

As this is an ongoing process, further development of the Teacher Seminar format is planned. The table below presents how different approaches to the Seminar were introduced and elaborated in a series of project meetings across the partner countries. This also includes the twin project MOSEM[2].

Level (Italy)	Level (Belgium)	Teacher trainer	Project	Teachers
experiencial	Activity	Extended preparations	SC2, MOSEM	Learn passive, content and skills, no long term success (unless pressure)
metacultural	Process	Extended support materials	MOSEM, MOSEM²	Learn more active, need help; content, skills and attitude success is questionable (unless pressure)
metacultural	Development	Support materials, as much as possible	MOSEM²	Have competencies, learn by exchange implementation is likely
situated	Manager	Support materials	Action research Udine in MOSEM	Have competencies, learn by exchange, self reflection and peer reviewing implementation is guaranteed

In coaching groups of collaborating teachers (in one school or coming from different schools) the goal is that the group evolves from the basic level to higher levels. At this stage collaboration has become structural, so they can become independent of coaching help.

Web resources for professional development of teachers

http://ww1.efqm.org/en/tabid/270/default.aspx
http://www.ba2c.com/documents/Informationefqm.pdf

Structure of the teacher seminar

The teacher seminar is set up as a series of 4 sessions. Two of them are mainly based on the LTK and two are based on the HTK. Session 1 and 2 have only one format, session 3 and 4 can have two formats or approaches. In short: one type is for teachers that need a lot of guidance, the other is for teachers that can learn more independently. The following tables presents each session and consists of information on time devoted to certain seminar's parts, its subjects, goals and associated materials together with remarks.

Session 1

This session mainly uses the Low-Tech Kit.

Time	Subject	Goals	Means/materials Remarks
5 min.	Introduction	Motivate to enhance teaching methods	Show trailer video on a research that has taken place at the Bonhoeffer college in Castricum (Netherlands), lead by P. Uylings Trailer (preferably of own country). Look at http://www.youtube.com/user/Zerezivil for the example.
15 min. Phase 1	Starter	Motivation	Active teaching methods - learning pyramid - see more further in the guide 1. Predict how effective each of the suggested teaching methods is 2. Compare your prediction with your neighbour 3. Look at the answers, which are based on research 4. Conclusion MOSEM_WP5_Session1_1_LearningPyramid_UA.doc
15 min. Phase 2	Introduction	Set the scene	Powerpoint Summary of the past projects and of materials available: MOSEM_WP5_Session1_2_Project_overview.ppt
30 min. Phase 3	Permanent magnets (small item)	**Prevent accidents, aware of safety**. Demonstration incorporates all aspects of using the MOSEM materials **Safety issues described further in the guide. See also remarks in certain activities.**	Safety issues on permanent magnets Experience one series of experiments: how to carry them out technically; how to teach students in the class rooms to do the experiments Link to the SC2 animations Link to local curriculum Discuss with colleagues Permanent magnets: Descriptions of series of exp. 3.3.x MOSEM_WP5_Session1_3_LP33x_demo_UA.doc MOSEM_WP5_Session1_30_SafetyStrongMagnets.doc

45 min. Integrated learning Phase 4	Theory learning paths:	Set the pedagogic-didactical framework of sessions. Pedagogical paths.	Overview of all experiments and learning paths included. MOSEM_WP5_Session1_4_UseActiveLearning_UA.doc MO_all_deliverables_overview.doc
	Theory on teaching strategies	Teachers get to know several methods of active learning suited for experimenting (and maybe others).	Active learning by students using safe experiments MOSEM_WP5_session1_40_TeachingStrategies_U.ppt List of possible strategies.
	What is Minds-on approach?	Study Minds-on as essential to the MOSEM project; consequences for teaching.	Discuss two articles and the way the descriptions are put together MOSEM_WP5_session1_41_Mindson_UA_20090906_WP.doc
			Study of connection between SC2, MOSEM projects and local curriculum Local curriculum is needed
Pause: 5 min			
5 min Theory on gender			
45 min.	Magnetic effect of current	Teachers experience active learning. Stress on MINDS-ON approach.	The document MOSEM_WP5_session1_41_Mindson_UA.doc gives an idea on how to behave as a trainer in order to make this strategy successful. Use Exp. series 3.5.x Use analogy between phenomena as a physics methodology. Links also to MOSEM²
40 min.	Lorentz force	Experience the series of experiments. Use video. Training in using the materials provided by SUPERCOMET2 and MOSEM.	Active learning method - look for all experiments - look for all additional materials - order them in a learning line Links to MOSEM² Exp. series 3.6.x Online Computer Application
10 min.	Example	Give an example of how basic materials can be put together to serve specific goals.	Examples from other countries Overview of the file that served as guide for a teacher seminar session in Graz: MOSEM_WP5_session1_42Example_workshop_graz.doc

Session 2

This session mainly uses the Low-Tech Kit.

Time	Subject	Goals	Means/materials Remarks
5 min.	Concept picture	To learn how a discussion can be started.	Show the concept picture and give pro's and cons of all statements. Timing of the session
60 min.	Induction	A conceptual approach leading from feeling induction processes to how generators work. Qualitative. Rich content.	Active learning: use one of the methods so that all participants at least perform several experiments. **Experiment series 2.3.x** Distance, electricity induced, changing magnetism, relative motion, applications, simulation are key words in this series of experiments MOSEM_WP5_Session2_1_LP2xx_Induction_UA.doc
50 min.	Separate view on the High-Tech experiments-introduction to superconductivity	MOSEM definition of High-Tech Kit and Low-Tech Kit. Give a framework for using the High-Tech Kit experiments. Connect to online application. Connect to Low-Tech Kit application.	Presentation of several experiments of the HTK: either in real time (if liquid nitrogen and the kit is available, else, show some films and explain how to the participants can get in touch with the experiments (either as teacher or with their students - link all previous Low-Tech experiments to the High-Tech ones: MOSEM_WP5_Session2_2_LP4x_Introduction_UA.doc - special attention to safety issues: MOSEM_WP5_Session2_SafetyLiquidNitrogen_UA.doc
Pause			
20 min.	Practical information on Low-Tech Kit		Look at all digital resources MOSEM_WP5_Session2_LowTechKit_PRACTICAL_UA.doc MOSEM_WP5_Session2_LowTechKit_PRACTICAL_UA.ppt
15 min.	Some possibilities on collaborative learning among teachers	Motivate teachers to join the forum.	Make sure several online pc's are available. Let people subscribe at the spot. It is possible to do so as they arrive, saving some time. International and national fora on MOSEM site How to subscribe: MO_forum_manual_registration.pdf Approve the subscriptions if possible (or agree with one of the administrators). Make sure you have some materials ready for them on the forum.
30 min.	Evaluation / discussion	Feedback on the teacher seminar and on the learning process of the teachers themselves.	MOSEM_WP5_Session2_questionnaire_Session1&2.doc

Session 3 and 4 (experiential – activity based)

The following two sessions are based on the HTK. In these sessions teachers collaborate with the teacher trainer in the following way:

- he fills out the student worksheets (where given) and gives feedback,
- he discusses with colleagues on goals and approaches,
- sessions 3 and 4 are combined (= 1 day/2 half days),
- teacher trainer guides all participants along all experiments.

Working with the High-Tech content of the HTK can be seen as an experiential activity. Most of the support materials (descriptions) are extended. The format is easy: perform all experiments in an interactive way, using the approach, questions etc. suggested in the descriptions and worksheets. This takes one day.

1st part: session 3

Time	Subject	Goals	Means/materials Remarks
5 min.	introduction Superconducting train	Attract attention. Fascinate participants for the subject of this training.	Demonstrate the superconducting train experiment, pointing at different "strange" observations that can be made. To explain the method, use MOSEM_WP5_Teacher_seminar_Session3_HTK_Intro_ExpAct_2009090631_WP.ppt
10 min.	EU promotes Life long learning Goals of the session	Make teachers in physics understand that knowledge evolves continuously. Motivate teachers that new knowledge is understandable with basic understandings of physics.	The EU strategy of LLP especially on vocational training of … physics teachers. Introductory powerpoint presentation.
15 min.	Introduction-timing-practical issues-organisation	Training in High-Tech experiments.	Timing of this session Registration is "obligatory", given the project goals and this type of seminar: MOSEM_forum_manual_registration_20090511_CB.pdf MOSEM_WP5_DigitalGuideOfDigitalMeans.xls
10 min.	Safety issues with LN		Safety issues are important. Poster on LN & ice cream.
45 min.	Conduction and temperature	Experience the series of experiments. Discuss with colleagues.	Interactive teaching+ demonstration+ minds on questions HTK Experiment series 4.1 HTK booklet with all experiments
30 min.	4.2 Persistent current Superconductivity (and QM)	Give teachers an up to date view on superconductivity. Link this to all previous "explanations". Discuss how to use this materials in the class room.	(Rehearsal of induction) Interactive teaching + demonstration + minds on questions. HTK Experiment series 4.2 HTK booklet with all experiments. Movies and applications.

Pause			
30 min.	3.2 Magnetism in different materials: permeability (ferro, para, diamagnetism)	Experience the series of Low-Tech experiments. Use video to show how to perform the experiments introduce diamagnetism. Build bridge between Low-Tech and High-Tech.	Interactive teaching + demonstration + minds on questions LTK experiments introducing the 3.2.x series:
30 min.	4.6: Gadolinium experiment Magnetism and	Experience the series of experiments. Discuss with colleagues.	Interactive teaching + demonstration + minds on questions. HTK Experiment series 4.6 HTK booklet with all experiments.
15 min.	Practical information on the kits (High-Tech)		Presentation is specific for each country. It is not clear at the moment how the teachers will be able to get in touch with the HTK . Data resources, MOSEM web, media repository.
Evaluation will be carried out after session 4			

2nd part: session 4

Time	Subject	Goals	Means/materials Remarks
15 min.	Introduction- timing-practical issues- organisation	Training in High-Tech experiments.	Timing of this session
5 min.	Safety issues, LN		Poster on LN & ice cream.
45 min.	4.5: Hall effect	Measuring magnetism.	HTK Experiment series 4.5
45 min.	4.3: Discovering levitation: Meissner, pinning Levitating experiments: Meissner, pinning + qualitative	Discussion.	Interactive teaching + demonstration + minds on questions. HTK Experiment series 4.3 HTK booklet with all experiments.
45 min.	4.4: Let the train fly: superconducting train		HTK Experiment series 4.4 HTK booklet with all experiments.
Extra	BINGO	Rehearsal of all 2 sessions.	Adapt the existing BINGO file to one that relates to the learning process in past two sessions. Overall version and the version that needs to be printed: MOSEM_WP5_Strategy_BINGO_print_WP5.doc
15 min.	Practical information on the High-Tech kits	Final Discussions on the two sessions as sessions.	Data resources, MOSEM web, media repository.
10 min.	Evaluation		MOSEM_WP8_Teacher_Seminar_questionnaire_Session3&4.doc

Session 3 and 4 (metacultural – process based)

The two sessions treat the same topics as before, but in a different way. These two sessions are also based on the HTK. In this session teachers work in groups of 3-4 people in the following way:

- they agree on tasks to be carried out by every member
- they agree on a work plan
- they use all available materials and discuss them
- sessions 3 and 4 are combined (= 1 day/2 half days)
- the teacher trainer is present for help if necessary

The HTK with its High-Tech content can be used in a metacultural process: most of the support materials (descriptions) are extended. Teachers as a group in principle go through the whole learning process, and do everything themselves, but guidance is necessary. The trainer is present at any moment. The group should be organized: who does what and when. All support materials are available.

1st part: session 3

Time	Subject	Goals	Means/materials Remarks
5 min.	introduction Superconducting train	Attract attention. Fascinate participants for the subject of this training.	demonstrate the superconducting train experiment, pointing at different “strange” observations that can be made. Explain the type of seminar using the file MOSEM_WP5_HTK_Teacher_Seminar_Scheme_Coll_Process.docx
10 min.	EU promotes Life long learning Goals of the session	Make teachers in physics understand that knowledge evolves continuously. Motivate teachers that new knowledge is understandable with basic understandings of physics.	The EU strategy of LLP especially on vocational training of physics teachers. Introductory ppt presentation. Warning: timing is not crucial here since the groups work rather independently Registration is "obligatory", given the project goals and this type of seminar: MOSEM_forum_manual_registration.pdf
15 min.	Introduction-timing-practical issues-organisation	Training in High-Tech experiments. Active learning, train research competencies, use MOSEM materials.	Method used = experiencial/activity based Each person gets a certain task: chairman, secretary, performer, reporter: the tasks rotate from one experiment to another. This document is for participants very important: MOSEM_WP5_DigitalGuideOf DigitalMeans.xls Experiments available: (not limited). The trainer can make as many experiments available as needed; he needs to coordinate so that none take the same (system of numbers or cards).
10 min.	Safety issues, LN		Safety issues are important. Poster on LN & ice cream.

Rotation system	4.1: R vs T : Conduction and temperature	Experience the series of experiments. Discuss with colleagues.	Collaborative independent work by the groups of teachers. HTK Experiment series 4.1 HTK booklet with all experiments
Rotation system	4.2 Persistent current Superconductivity (and QM)	Give teachers an up to date view on superconductivity. Link this to all previous "explanations". Discuss how to use this materials in the class room.	(Rehearsal of induction) Collaborative independent work by the groups of teachers. HTK Experiment series 4.2 HTK booklet with all experiments. Movies and applications.
Pause			
Rotation system	3.2 Magnetism in different materials: permeability (ferro, para, diamagnetism)	Experience the series of Low-Tech experiments. Use video to show how to perform the experiments introduce diamagnetism. Build bridge between Low-Tech and High-Tech.	This item can be skipped. If HTK training is given apart, however, it seems to be necessary to make the Low-Tech Kit known. Collaborative independent work by the groups of teachers. LTK experiments introducing the 3.2.x series:
Rotation system	4.6: Gadolinium experiment Magnetism	Experience the series of experiments. Discuss with colleagues.	Collaborative independent work by the groups of teachers. HTK Experiment series 4.6 HTK booklet with all experiments.
all remaining time	Reporting on activities and findings in presentation	Synthesis of group work; inspire each other Each reporter has 5 minutes.	Beamer is available. Reports on the forum => international community.
15 min.	Practical information on the kits (High-Tech)		Presentation is specific for each country. It is not clear at the moment how the teachers will be able to get in touch with the HTK. Data resources, MOSEM web, media repository.
Evaluation will be carried out after session 4			

2nd part: session 4

Time	Subject	Goals	Means/materials Remarks
15 min.	Introduction-timing-practical issues-	Training in High-Tech experiments.	Timing of this session
5 min.	Safety issues, LN		Poster on LN & ice cream.
Rotation system	4.5: Hall effect	Measuring magnetism.	HTK Experiment series 4.5
Rotation system	4.3: Discovering levitation: Meissner,		Interactive teaching + demonstration + minds on questions. HTK Experiment series 4.3 HTK booklet with all experiments.
Rotation system	4.4: Let the train fly		HTK Experiment series 4.4 HTK booklet with all experiments.
Extra	BINGO	Rehearsal of all 2 sessions.	Adapt the existing BINGO file to one that relates to the learning process in past two sessions. Overall version and the version that needs to be printed: MOSEM_WP5_Strategy_BINGO_print_WP5.doc
All remaining time	Reporting on activities and findings in presentations-discussions	Synthesis of group work; inspire each other Each reporter has 5 minutes.	Beamer is available. Reports on the forum => international community.
45 min.	Practical information on the High-Tech kits	Final Discussions on the two sessions as sessions.	Data resources, MOSEM web, media repository.
10 min.	Evaluation		MOSEM_WP8_Teacher_Seminar_questionnaire_Session3&4.doc

Pedagogical paths to superconductivity

Path 1 - Exploring magnetic properties

Assemble the necessary materials that are needed to follow the path described below.

1. Find which SUPERCOMET online modules/slides are needed, and where the LTK experiment descriptions, the films, (models, simulations) and other materials are to be found;
2. Integrate the worksheets for students if available;
3. Focus on Minds-on approach and determine where to find this in the deliverables that you found.

The thread of the contents will be presented with its segments (M1-M8) indicating in parentheses the experiment codes carried out by the students.

M1 – The interaction of a magnet with different materials is explored (Exp. 3.1 / 3.2). The different materials can be sorted into two groups: 1) iron, steel, or nickel (ferromagnetic), 2) non metals and many metallic objects e.g. copper, bronze and aluminium. It is recognized that not all metals exhibit ferromagnetic properties. Exploration of the interaction is completed with the recognition of the dependence on distance. The ability of a magnet to modify the surrounding space introduces the magnetic field, which is represented by means of field lines constructed using small compasses, iron filings or a single compass (Exp. 3.1.1 / 3.2.1). Such a representation gains formal meaning when it is observed that the density of lines can be correlated to the measured field intensity.

M2 – The interaction between two magnets is explored (Exp. 3.3.4 / 3.3.9 / 2.3.8): ring-shaped magnets are stacked above each other, by means of a wooden bar and bar-magnets, being free to rotate, are facing each other pole to pole. By using the guided exploration, students should:
recognise the bipolar nature of the magnets; be able to construct the force-distance relationship between the poles of magnetic rods (Exp. 3.3.5); recognize the role of a pair of forces in the interaction (Exp. 3.3.6).

M3 – While cylindrical magnets fall with acceleration down a vertical or inclined plastic pipe or copper pipe with slits, they move more slowly when falling down a copper pipe, or a pipe made of other conducting material. The recognition of the role played by the EMF and then of the induced currents in the copper pipe, or a pipe made of other conducting material leads to the interpretation of the phenomenon. The magnetic field produced by the induced, current has the opposite direction to that of the falling magnet and is responsible for the slowing down of the magnet. The experiment is carried out with a standard copper pipe and then with a pipe with slits (Exp. 2.3.5 / 2.3.8). This can effectively lead to a quantitative analysis. (Exp 2.3.8).

M4 – The phenomena of electromagnetic induction and of magnetic suspension are reconsidered by studying the Thompson ring experiment (Exp. 3.5.10). This shows the influence of T on ρ (Exp. 1.2.6). The experiment, repeated with rings of different materials allows students to recognize that there is an analogous behaviour due to the strong field produced by the induced currents, which are higher when the temperature is reduced. The evident decrease of resistivity is then associated to the decrease of temperature of the ring material.

M5 – By analogy with the Thomson ring experiment, the behaviour of a magnet above a cooled superconductor is explored (Exp. 4.3.1). The levitation of the magnets is compared with the analogous situations observed before: the experiment of the floating magnets suggests that the magnet must be subjected to an opposite field; the experiment of the falling magnet down the copper pipe indicates that the effect tends to be self regulating, i.e. it is produced by an induced field; the fact that the magnet levitates but does not fall, as in the case of the magnet in the copper pipe, indicates that the induced field must be equal to the inducing field, or that the superconductor behaves as a perfect diamagnetic, this is the Meissner effect. The effect of induction produced by the presence of the magnet does not stop when the magnet is still, as happens with an ordinary conductor. In the superconductor the dissipative effects must therefore be absent, or $\rho \sim 0$. Measurement of $\rho = \rho(T)$ (Exp. 1.2.6 / 4.1).

M6 – The experimental exploration of the Meissner effect (Exp. 4.3.1) introduces the main events leading to the discovery of superconductivity, characterizing type I and II superconductors (Exp. 4.3.2), describing the anomalous behaviour of the three quantities which exhibit critical values in superconductors: magnetic field, current and temperature.

M7 – A short review of the technological applications of superconductors offers the opportunity for interdisciplinary connections of various types, giving the relevance of the use of superconductors in the electronics and sensor fields, cryoelectronics and superconducting sensors, medical diagnostics (NMR) and in advanced physics research e.g. superconducting magnets.

M8 – The explorations in segments M6 and M7 suggests the discussion about the basic elements of the BCS theory, the only one that accounts for I type superconductors. Within this theory the role played by the lattice in the production of net attractive effects between electrons, i.e. in the formation of the Cooper pairs, can be discussed. In addition the effect of condensation of such pairs, not being subject to the exclusion principle, can also be discussed.

Path 2 - Exploring resistivity

Assemble the necessary materials that are needed to follow the path described below.

1. Find which SUPERCOMET online modules/slides are needed, and where the LTK experiment descriptions, the films, (models, simulations) and other materials are to be found;
2. Integrate the worksheets for students if available;
3. Focus on Minds-on approach and determine where to find this in the deliverables that you found.

Examples of pedagogical paths on introduction of superconductivity in high-schools implemented in Italian schools in the experimentations coordinate by the University of Udine in the framework of the SUPERCOMET - MOSEM projects.

This path develops in the steps (R1-R5) discussed below. Experiment codes are given in parentheses for those proposed and realized with students.

R1 Experimental exploration of the V-I relation for ohmic elements: Ohm's law and revision of the behavior of currents measured in simple resistive circuits. From resistance to resistivity ρ as an electrical property of materials and generalized Ohm's law (Exp. 1.1.1).

R2 The experimental study of ρ vs T (Exp. 1.2.6 / 4.1.1) offers the opportunity of discussing the microscopic model of the Fermi gas to describe the conduction in metals at room temperature.

R3 The problem of studying the behavior of ρ(T) near 0 K has been posed. The residual resistivity ρ_r = const. due to defects and impurities of metals disappears in superconductors. The focus on the critical transition, reached in the laboratory for a type II superconductor immersed into liquid nitrogen, allows the sharp phase transition of the superconductor, responsible of the resistivity fall, to be observed (Exp. 4.1.2).

R4 The sharp change of conduction properties in a small temperature interval provides evidence of the phase transition nature of the process. An interpretative model for such transition is then given and the BCS model for I type superconductors discussed.

R5 A simulation allows the electric circuits explored in step R1) to be reanalysed, substituting an ordinary resistive element with a superconductor:
a) to reproduce the experimental conditions, assigning the values of the resistors employed in the laboratory;
b) to examine, point by point, the resistivity vs temperature, down to the sharp fall at T=Tc, for the recognition of the qualitative and quantitative change in circuit behavior;
c) to analyse the redistribution of the voltage drops at the extremes of the various circuit elements, recognizing the role and the function of the superconducting elements.

Path 3 – Energy transformations

Assemble the necessary materials that are needed to follow the path described below.

1. Find which SUPERCOMET online modules/slides are needed, and where the LTK experiment descriptions, the films, (models, simulations) and other materials are to be found;
2. Integrate the worksheets for students if available;

3. Focus on Minds-on approach and determine where to find this in the deliverables that you found.

Examples of pedagogical paths on introduction of superconductivity in high-schools implemented in Italian schools in the experimentations coordinate by the University of Udine in the framework of the SUPERCOMET - MOSEM projects.

The detailed path is described by following steps (E1-E5), indicating the relevant experiment codes in parentheses.

E1 In the context of energy transformation into different forms, the electric energy transformations in particular are analysed. It is recognized that there are different ways, static and dynamic, to produce electrical energy (Exp 3.6.3 / 3.6.4 / 3.6.5). The electrostatic and magnetostatic fields are explored and compared (Exp. 3.3.2 / 3.3.3 / 3.4.2). The experimental exploration of DC circuits, with traditional instruments and on-line sensors (Exp. 1.1.1), is integrated with the discussion of the SC-CD 4th module. The phenomenology is described through the first and the second Ohm's laws and their limits are discussed considering the I-V characteristic of a bicycle lamp (Exp. 1.2.4) and discussing the energy transformation processes (Joule effect).

E2 The magnetic effect of an electric current is introduced with qualitative experiments (Exp.3.5.1 / 3.5.2) and one of the SUPERCOMET online learning modules, integrated with an activity of formalization. The fields generated by magnets are visualized by constructing the field lines with iron filings and compasses. The Oersted experiment is completed with the Biot-Savart law for a straight wire. The magnetic fields produced by currents are developed both in terms of formalization and description by the experimental and simulated exploration of the Ampère (Exp. 3.5.3) and the Pohl experiments (Exp. 3.6.1).

E3 The description of the magnetic effects of currents is completed by analyzing the filed produced by coils and magnets, first experimentally in the laboratory (Exp. 3.1.1 / 3.1.2), then by using the module 2 simulations of SC-CD.

E4 The students, in groups, explore ways to generate an induced EEMF (Exp 2.1.1 / 2.2.1). The concept of flux is introduced and clarified. The transformer and the dynamo (Exp. 3.6.6) are analysed and the concepts of induction and alternating current are revisited. The energy transfer processes involved in transformers are then analysed.

E5 In groups, the students explore the interaction between stacked magnets (Exp. 2.3.6 / 2.3.7) and various situations of levitation of a magnet on a superconductor (Exp. 4.3.2). With the same strategy previously adopted the experimental exploration and the superconductivity interpretation are integrated, discussing in particular the formation of the Cooper pairs. A short discussion about the application of superconductivity completes the path.

Path 4 - Exploring applications

Assemble the necessary materials that are needed to follow the path described below.

1. Find which SUPERCOMET online modules/slides are needed, and where the LTK experiment descriptions, the films, (models, simulations) and other materials are to be found;
2. Integrate the worksheets for students if available;
3. Focus on Minds-on approach and determine where to find this in the deliverables that you found.

The steps (A1-A6) below outline the path. Experiment codes to be carried out by the students are given in parentheses.

A1 A preliminary phase recalls the main knowledge about electric conduction: simple circuits with linear elements are taken into consideration to reconstruct Ohm's law (Exp. 1.1.1). The relation between resistivity and temperature is experimentally explored and recognized (Exp.1.2.6).

A2 The theme of superconductivity is introduced with the videos of Maglev, MNR, magnetic bearings and supercomputers. Such videos motivate the explanatory investigation. The experiment showing magnetic levitation (Exp.4.3.1), allows the behavior of a perfect diamagnet to be recognized in a superconductor: the Meissner effect that is used for an experimental exploration about the behavior of a superconductor with temperature. T_c is recognized and measured (Exp.4.3.3).

A3 The extraordinary behavior of a superconductor for temperatures lower than T_c leads to an exploration of the properties of a superconductor and in particular those of electric conduction. The main elements characterizing the superconducting phenomenology are discussed: the existence of a critical temperature T_c, of a critical field and of a critical current; the penetration coefficient.

A5 A simple electric circuit employing a superconductor switch is the context that is proposed for the recognition of the fact that also the resistance of a superconductor circuit element undergoes a sharp variation around T_c. The relation between resistance and temperature for a superconductor around T_c is then experimentally explored (Exp. 4.1.2). With the help of an oscilloscope or of on-line sensors, the potential difference at the extremes of various circuit elements containing at least one superconductor is measured (Exp. superconductor switch). The measurement of the current in the various segments of these simple circuits, in particular in the segment where is present the superconductor element, allows the critical current, above which the superconductor returns to the ordinary conducting state, to be determined.

A6 A simple apparatus allows a Maglev to be simulated, allowing for exploration of its functioning (Exp. 4.4).

Activity descriptions

Descriptions of activities/experiments

Different types of activities with the Low-Tech Kit and High-Tech Kit have been prepared for use during Teacher Seminars and further in schools when teaching electromagnetism and superconductivity with the Minds-on approach:

- Low-Tech Kit (materials for basic electromagnetic experiments)
- High-Tech Kit (advanced materials including superconductors that require a supply of liquid nitrogen).

Each activity is numbered and associated with information linking the subject to online modules and specific physics topics. A set of Minds-on questions play an essential role in facilitating the active learning we want to induce.

Low-Tech Kit activity descriptions contain:

- Number - each activity is numbered and associated with information linking the subject to on-line modules and specific physics topic,
- Learning objectives and Set-up – presenting learning objectives and set-up details/pictures of each described experiment helps teachers and students in using the activity,
- Activity description – consists of the proposal for activities to be performed with the set-up,
- Minds-on questions – the list of Minds-on questions empathizes intended use of the LTK,
- Evaluation of LTK materials and activity description – here some evaluation comments are listed.

High-Tech Kit activity descriptions contain:

- Pedagogy and Set-up – with remarks on how to approach the activity from the pedagogic point of view together with set-up details/pictures of each described experiment,
- Observations –detailed information on what to observe,
- Minds-on questions –emphasizes intended use of the experiments,
- The physics of the experiment – with main physics information and principles that help understanding the observed behaviour.

High-Tech Kit Student Worksheets contain:

- Number - each activity is numbered and associated with information linking the subject to on-line modules and specific physics topic,
- Safety Issues –important information concerning use of materials,
- Aim – this part present main pedagogical aims associated with the activity,
- Apparatus – where the set-up of the activity is described,
- Procedure –descriptions of the experiment with Minds-on questions.

High-Tech Kit Student Explanation sheets consist of basic physics information and principles allowing teacher and students understand the carried out experiment.

Safety warnings for superstrong magnets

Liability statement

The superstrong NdFeB magnets in the Low-Tech Kit and High-Tech Kit delivered by Simplicatus Research and Development AS are supplied by Webcraft GmbH[12]. Simplicatus Research and Development AS and Webcraft GmbH do not accept responsibility for damage that has been caused by the improper handling of magnets. By using such magnets from a Low-Tech Kit or High-Tech Kit, you confirm that you have read and understood the following warnings. Ensure that children know the potential dangers of the magnets.

Personal safety warnings

Danger of crushing

Larger magnets, when they are brought close enough together, can have a surprising amount of power. Fingers are quickly caught between strong magnets, causing cuts, blood blisters or crush damage. Wear gloves when handling larger magnets and use caution. Practice handling smaller magnets first. You are strongly advised against attaching magnets to earlobes, nose or other body parts.

Danger for children

In addition to the above dangers, children might insert the thinner magnets into a power outlet. Make sure to supervise children whenever they play with the magnets. Keep larger magnets out of children's reach, as you would sharp knives or other dangerous materials. Because of the danger of being swallowed, NdFeB magnets are not suitable as toys for children under the age of nine. If swallowed, smaller magnets can get stuck in the intestines and cause life-threatening injuries.

Danger from breaking or chipping

NdFeB magnets break quite easily. The most common cause of breakage is when two magnets are allowed to collide. In particular when a disc magnet and a strong sphere magnet collide, the disc magnet is not likely to survive. It is also conceivable that sharp chips of the magnet will fly due to such a collision. You should wear gloves and protective glasses when handling larger magnets. You should always handle magnets with caution and never let them collide together.

Nickel allergies

Most NdFeB magnets are nickel-plated. Nickel is a metal which can cause an allergic reaction in some people. Nickel allergies can be acquired through long-term contact with objects that release nickel. In most cases, these allergic reactions are triggered by nickel-containing jewellery (e.g., earrings or piercings, clips, rings or necklaces). As a precaution, avoid long term contact with nickel-plated magnets (e.g. as jewellery) and totally abstain from contact with nickel-plated materials if you already have a nickel allergy. How much or little it takes to trigger a nickel allergy is debatable (note the discussions regarding the Euro coins which contain 25% nickel).

[12] This text is based on the safety warning text at supermagnete.de, our supplier of these magnets.

Other issues

Magnetic effects on people

Whether permanent magnets have an influence on the human organism is debatable. Therapists who use the magnets for medicinal purposes will naturally answer in the affirmative. Scientific studies have shown that the power of permanent magnets is too weak to be able to cause a measurable effect on humans. However, this is not a final conclusion and it's totally possible that this subject will be evaluated differently in the future due to new methods of measurement. The discussion of whether its influence on humans is beneficial or damaging is another story. If you'd like to play it safe, then avoid long-term contact and keep large magnets at least 1 meter away from your body.

Danger for appliances

NdFeB magnets are much stronger than "ordinary" magnets. Keep a safe distance between the magnets and all appliances and objects that can be damaged by magnetism. This includes, amongst other things, credit cards, television and computer monitors, magnetic tapes or diskettes for data, sound and video, mechanical clocks and other mechanical appliances made of magnetic materials, loudspeakers and other electronic or magnetic appliances. Hearing aids, metallic implants and pacemakers can be disturbed by large magnets - exercise caution.

Fire and heat sources

Keep the magnets away from open flames and any heat sources. The magnetisation of neodymium magnets reduces quickly at temperatures of more than 80 degrees Celsius.

Wearing or chipping of the surface coating

NdFeB magnets are usually plated with a thin layer of nickel, gold or silver. This plating can wear away in the course of normal use. In particular, the repeated collision of sphere magnets with each other results in extreme pressure at the point of contact, which inevitably leads to a loss of surface coating or even chipping. Large sphere magnets should be stored separated from each other with cardboard or a piece of soft paper, and should not be allowed to lie on metal surfaces for too long.

Processing, drilling and sawing

NdFeB magnets can be secured with glue or, better, countersunk and glued. You should never attempt to cut or drill into a magnet. First, the magnets will break. Second, this cutting or boring will produce a poisonous and easily flammable dust. The magnets should only be machined with special diamond tools and while water-cooled.

Low-Tech Kit Workbook

Overview and contents

This section shows all the elements of the Low-Tech Kit (LTK), with names and item numbers that will be used as references in the following activity descriptions.

The kit weighs about 23 kg and consists of the following main parts:

- Trolley with wheels, telescope handle, lock and keys
- Two upper trays with inclined plane, experiment table and other parts
- A main compartment with equipment, tools, tubes, magnets and 3 boxes
- Box with small non-magnetic items
- Small box with strong magnets, etc
- Small box with wires, etc

The trolley has a 7 year warranty. We have found that the telescope handle can break if you use it to lift the trolley. Please use the built-in handles on the top and the side to carry the trolley.

Low-Tech Kit parts

The Low-Tech Kit contains a total of 374 parts, and the list of contents uses a combination of letters and numbers to identify each item. The letter indicates which part of the kit the item is located in, and the items in the same location are then numbered.

Lid and top

In the lid

- Lock, keys and instructions for trolley

On the top of the upper tray

- **T1** Foam bevel for inclined plane
- **T2** Wooden plate for inclined plane

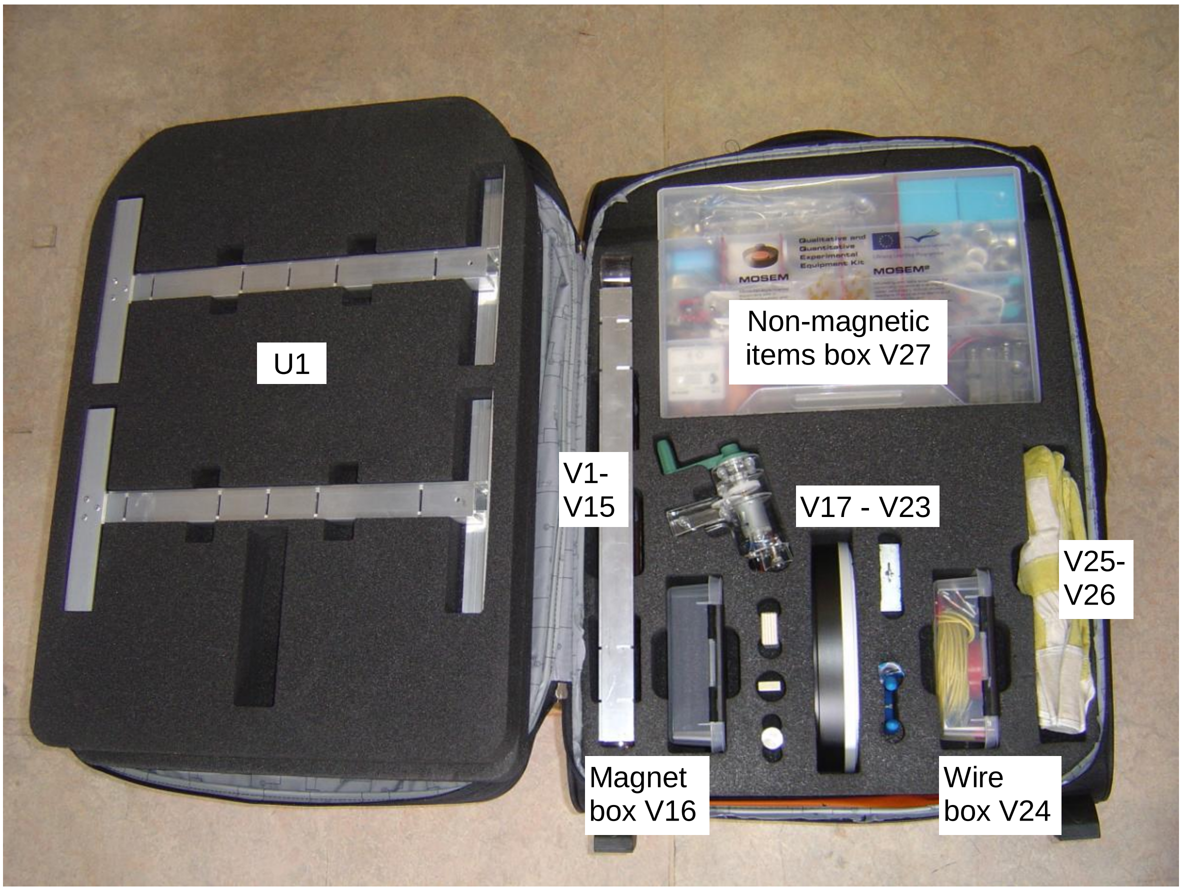
Upper tray

T3 Aluminium foil of length 50cm
T4 Magnetic field viewer / Flux detector, 15cm x 15cm
T5 MagnetShield film, 50cm x 102mm x 2.5mm, 2 pcs
T6 Plastic ruler, 50 cm
T7 Experimental table part 1 - plexiglass plate 400mm x 300mm x 3mm
T8 Experimental table part 2 - aluminium plate 400mm x 300mm x 3mm
T9 Experimental table part 3 - plexiglass plate 200mm x 300mm x 3mm, 2 pcs
T10 Experimental table part 4 - aluminium plate 200mm x 300mm x 3mm, 2 pcs
T11 Aluminium disc, Ø = 300mm with hole of 4.2mm
T12 Aluminium disc, Ø = 300mm with hole of 4.2mm and 12 slits (6 long and 6 short)

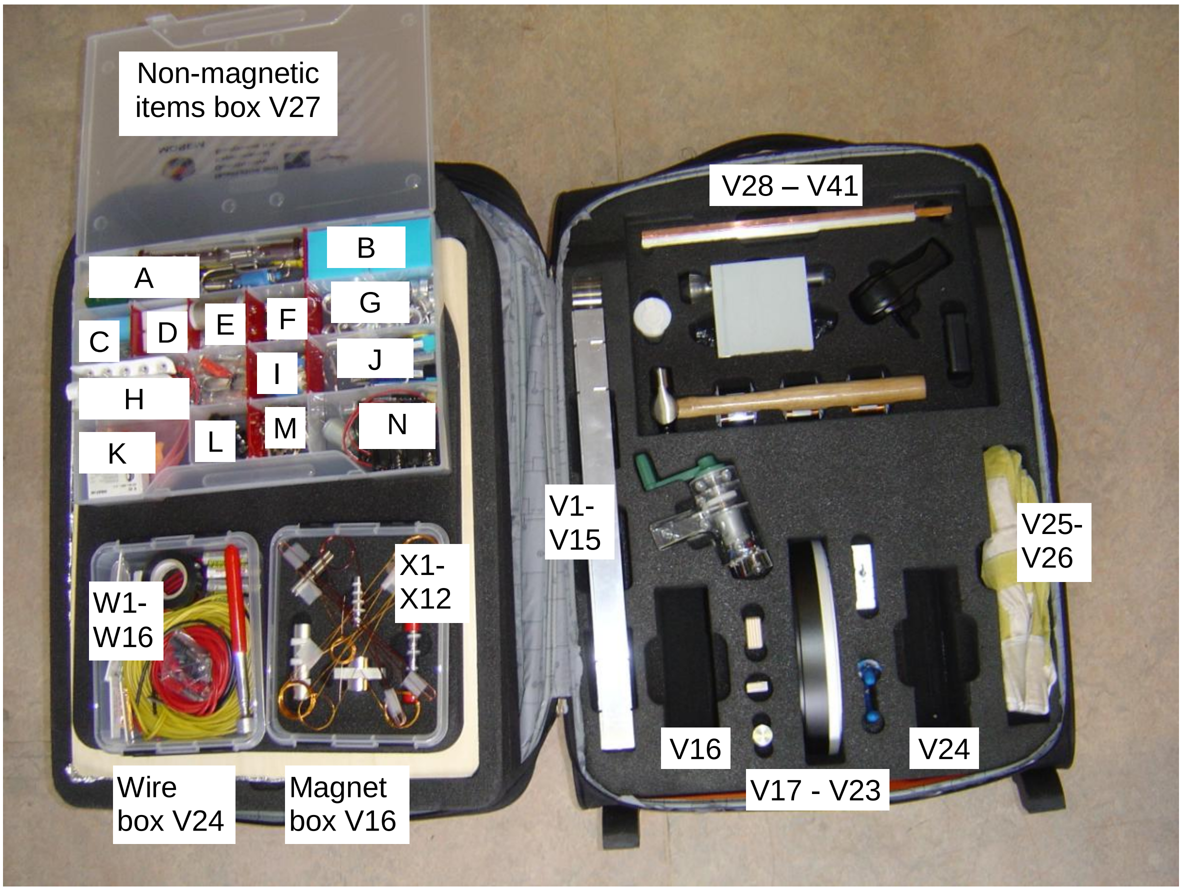
Middle tray and boxes

See photos on the next page.

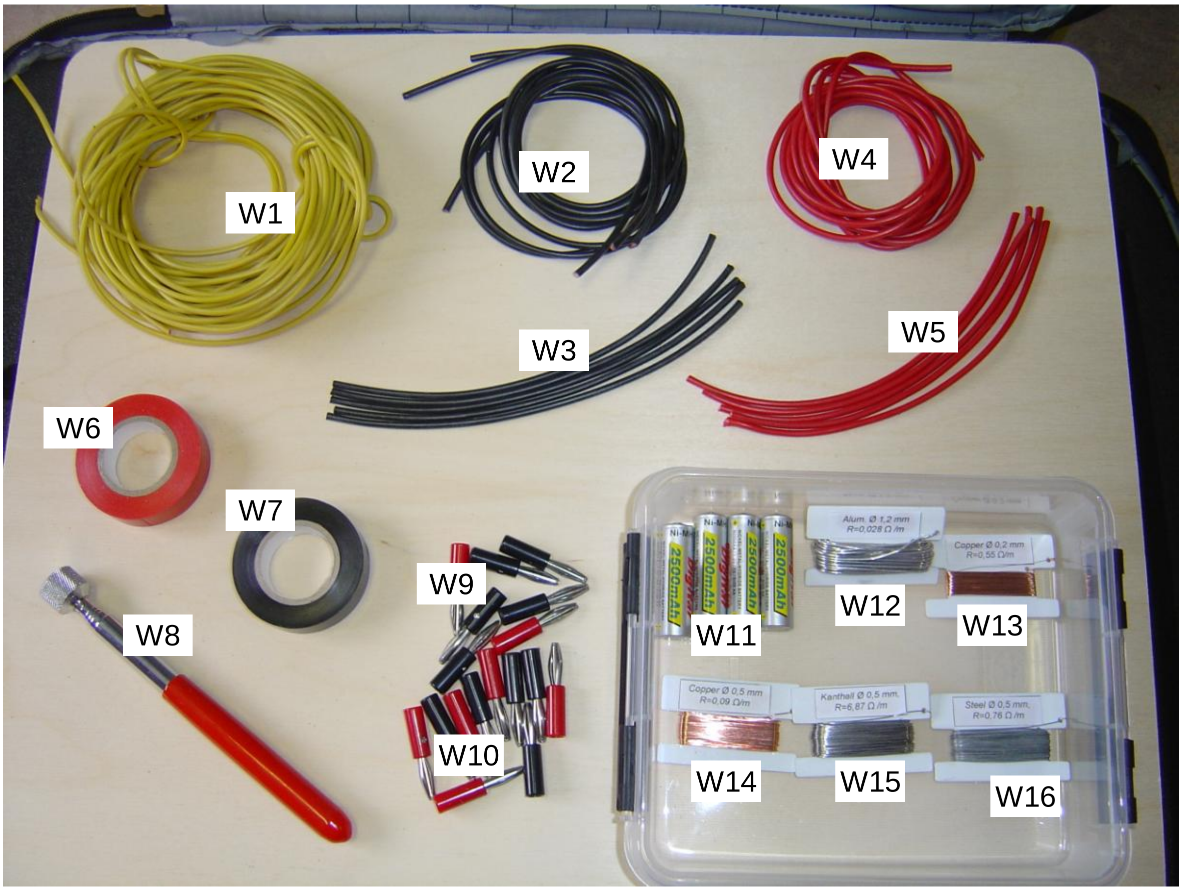
U1 Experiment table part 5 – Al table leg with 3.1mm slits and 4.1mm holes, 4 pcs
V16 Plastic box for magnets *(containing items X1-X12)*
V24 Plastic box for wires *(containing items W1-W16)*
V27 Plastic box for small non-magnetic items *(containing items A1-N3)*



Main compartment – overview

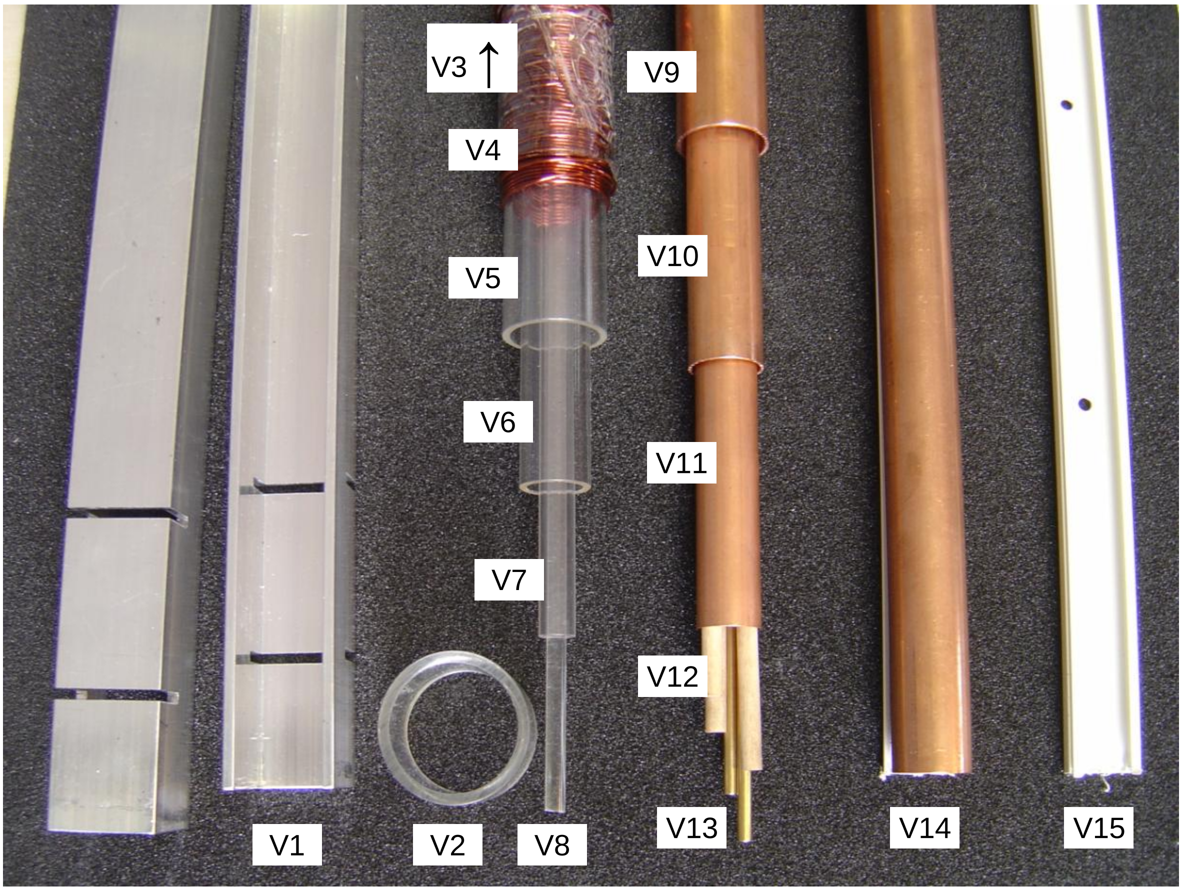


Box with wires, batteries and telescopic magnet



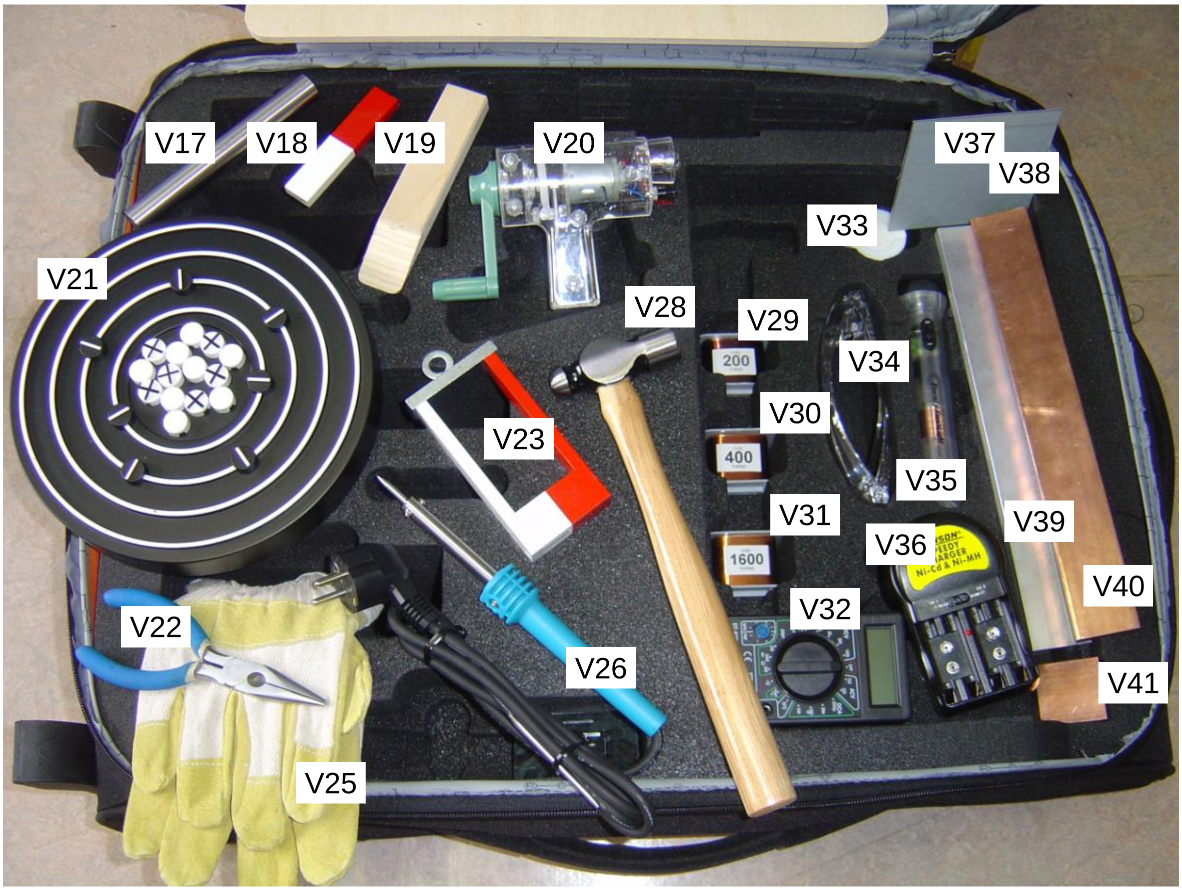
W1 Yellow lab wire Ø = 1.5mm, 10m, 2 pcs
W2 Black lab wire Ø = 2.5mm, 1.0m, 3 pcs
W3 Black lab wire Ø = 2.5mm, 20cm, 5 pcs
W4 Red lab wire Ø = 2.5mm, 1.0m, 3 pcs
W5 Red lab wire Ø = 2.5mm, 20cm, 5 pcs
W6 Red plastic tape
W7 Black plastic tape
W8 Telescopic rod magnet
W9 Black banana stick, 10 pcs for lab wires (W1, W2 and W3)
W10 Red banana stick, 8 pcs for lab wires (W4 and W5)
W11 1.2V rechargeable batteries, 4 pcs
W12 Aluminium wire Ø = 1.2mm, 10m
W13 Copper wire Ø = 0.2mm, 10m
W14 Copper wire Ø = 0.5mm, 10m
W15 Kantal wire Ø = 0.5mm, 10m
W16 Steel wire Ø = 0.5mm, 10m

Tubes and crossbar for experimental table



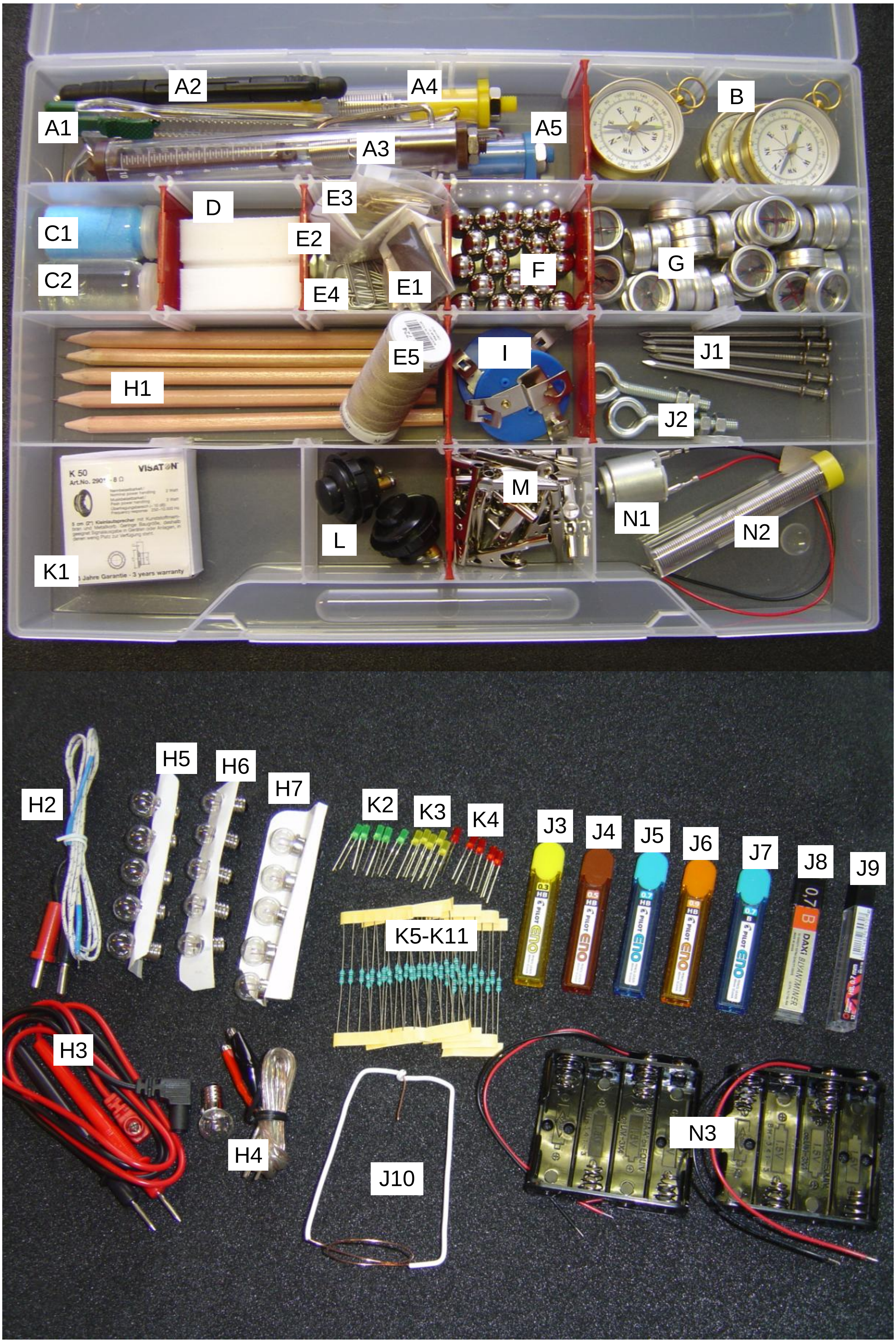
V1 Experimental table part 6 - Al crossbar with slits of 3.1mm for table legs, 2 pcs
V2 Plexiglass ring, Ø = 40mm
V3 Constantan wire Ø = 0.5mm, 1.0m (wrapped around V5)
V4 Cu wire Ø = 1.0 mm, 10m (wrapped around V5)
V5 Plexiglass tube Ø = 30mm, 50 cm
V6 Plexiglass tube Ø = 20mm, 50 cm (inside V5)
V7 Plexiglass tube Ø = 10mm, 50 cm (inside V6)
V8 Plexiglass rod Ø = 6mm, 35 cm (inside V7)
V9 Cu tube Ø = 28mm, 50 cm
V10 Cu tube Ø = 22mm, 50 cm with slits (inside V9)
V11 Cu tube Ø = 18mm, 50 cm (inside V10)
V12 Wooden rod Ø = 6mm, 50 cm, 3 pcs (inside V11)
V13 Brass rod Ø = 4mm, 50 cm, 2 pcs (inside V11)
V14 Cu tube Ø = 22mm, 50 cm
V15 Flexible plastic U profile, 50 cm

Main compartment – detailed view of items



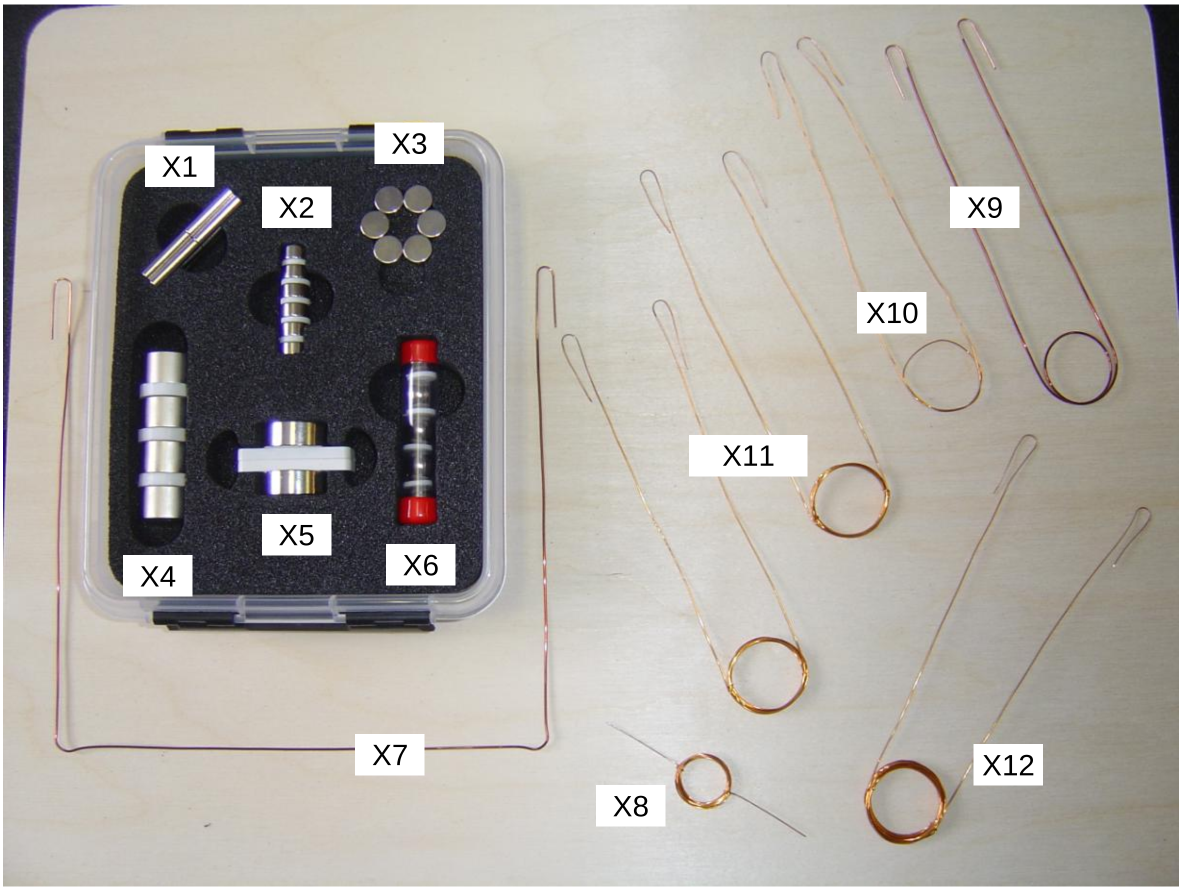
V17 Steel rod
V18 Bar magnet
V19 Wooden magnet separator
V20 Hand generator
V21 Model of the atom
V22 Wire cutter / pair of pliers
V23 U magnet
V25 Protective gloves
V26 Soldering iron
V28 Hammer
V29 Solenoid 200 windings
V30 Solenoid 400 windings
V31 Solenoid 1600 windings
V32 Digital multimeter
V33 Box with iron filings, 250g
V34 Protective goggles
V35 Linear induction flashlight
V36 Battery charger
V37 Aluminium plate, 102mm x 102mm x 1mm
V38 Steel plate, 102mm x 102mm x 1mm
V39 Aluminium bar 300mm x 40mm x 10mm
V40 Copper bar 300mm x 40mm x 10mm
V41 Copper bar 40mm x 40mm x 10mm

Box with non-magnetic items



A1 Small knife
A2 Pocket screwdriver
A3 Force meter / Newton-meter 50N
A4 Force meter / Newton-meter 10N
A5 Force meter / Newton-meter 2.5N
B Compass Ø = 50mm, 6 pcs
C1 Glass container with $CuSO_4$
C2 Glass container with water
D Foam with groove for magnet sticks, 2 pcs
E1 Pyrolytic graphite
E2 Iron nail 14mm, 25 pcs
E3 Small brass paper clip, 25 pcs
E4 Large steel paper clip, 10 pcs
E5 Thread
F Steel sphere Ø = 12,7mm Ø, 20 pcs
G Compass Ø = 20mm, 30 pcs
H1 Regular pencil w/o eraser, 5 pcs
H2 Temperature probe (K type, white cable) for digital multimeter (V32)
H3 Cables (red and black) for digital multimeter (V32)
H4 Cable and spare bulb for hand generator (V20)
H5 Bulb 1.5V, 5 pcs
H6 Bulb 2.5V, 5 pcs
H7 Bulb 4.8V, 5 pcs
I Bulb holder, 2 pcs
J1 Iron nail 75mm, 5 pcs
J2 Set of 2 eyescrews with 4 nuts for ring magnets (X4)
J3 Graphite sticks 0.3 HB, 12 pcs
J4 Graphite sticks 0.5 HB, 12 pcs
J5 Graphite sticks 0.7 HB, 12 pcs
J6 Graphite sticks 0.9 HB, 12 pcs
J7 Graphite sticks 0.7 B, 12 pcs
J8 Graphite sticks 0.7 B, 12 pcs
J9 Graphite sticks 0.7 HB, 12 pcs
J10 One loop motor frame
K1 Speaker Ø = 50mm
K2 Green LED, 5 pcs
K3 Yellow LED, 5 pcs
K4 Red LED, 5 pcs
K5 Resistor 1Ω, 5 pcs
K6 Resistor 10Ω, 5 pcs
K7 Resistor 100Ω, 5 pcs
K8 Resistor 400Ω, 5 pcs
K9 Resistor 2kΩ, 5 pcs
K10 Resistor 30kΩ, 5 pcs
K11 Resistor 100kΩ, 5 pcs
L Electrical switch, click type, 2 pcs
M Crocodile clip for banana stick, 20 pcs
N1 Electrical motor
N2 Soldering tin
N3 Battery holder, 4xAA, 2 pcs

Box with strong magnets and copper coils



X1 12 magnet sticks Ø = 5mm, 25mm long
X2 6 cylindrical magnets Ø = 12mm, 6mm long - vertical poles
X3 6 cylindrical magnets Ø = 12mm, 6mm long - horizontal poles
X4 2 pairs of S/N,N/S ring magnets
X5 2 cylindrical magnets Ø = 30mm, 10mm long
X6 5 magnetic spheres Ø = 13mm
X7 Pohl's swing, copper wire Ø = 1mm (+paper clips for suspension)
X8 Paper clip motor / straight copper wire Ø = 0.5mm with loops
X9 Copper loop Ø = 30mm, 1 turn, wire Ø = 1.0mm
X10 Copper loop Ø = 30mm, 1 turn, wire Ø = 0.5mm
X11 Copper loop Ø = 30mm, 10 turns, wire Ø = 0.5mm, 2 pcs
X12 Copper loop Ø = 30mm, 20 turns, wire Ø = 0.5mm

List of LTK experiments

The rich contents of the Low-Tech Kit can be combined and used in many more activities than those we have been able to describe in this workbook. The numbers in the below list of described experiments refer to a universal numbering system for all envisioned experiments and activities in both MOSEM and MOSEM^2 projects.

Numbers that are not included below refer to activities that are not described in this booklet. Some of them are described to the Teacher Guide for MOSEM^2, and others will be included in future versions of the MOSEM Teacher Guide.

1. Conduction

1.1 Conduction in solids, liquids and gases

1.1.1 Conduction in wires
1.1.5 Microscopic model of conduction in solids

2. Electromagnetic induction

2.2 Moving magnet

2.2.1 Stationary solenoid, moving magnet (along common axis)
2.2.2 Oscillating magnet in a coil
2.2.3 Falling magnet through a coil

2.3 Eddy currents

2.3.1 Lazy pendulum
2.3.2 Electromagnetic brake
2.3.3 Magnetic slalom
2.3.4 Sliding magnet
2.3.5 Magnet falling down copper tubes
2.3.6 Stack of magnets falling down copper tubes
2.3.7 Magnets falling down different tubes
2.3.8 Magnet falling on copper/aluminium bar
2.3.9 Chaotic pendulum

2.5 Applications

2.5.2 Generator

3. Magnetism

3.1 Magnetic poles

3.1.1 Exploring magnetic field and field lines
3.1.2 Magnetic sticks and balls

3.2 Magnetic materials

3.2.1 Iron filings and flux detector
3.2.2 Pencil stick exploration
3.2.3 Pyrolytic graphite levitation
3.2.4 Magnetic carousel (H_2O-$CuSO_4$)
3.2.5. Levitating magnet (Cu-Cu bars with magnet in between)
3.2.7. Magnetic shielding

3.3 Permanent magnets

3.3.1 Magnetic dog
3.3.2 Magnetic field with filings/small compasses
3.3.4 Magnets floating on the water
3.3.6 Repelling force: measurement with gravity
3.3.11 Interaction between two magnets
3.3.12 Gauss cannon

3.4 Earth magnetic field

3.4.1 The unwilling magnet
3.4.5 Rolling magnetic ball

3.5 Magnetic effect of current

3.5.1 Magnetic field from a wire (Ørsted experiment)
3.5.2 Ørsted experiment, horizontal version
3.5.3 Magnetic force between parallel wires (Ampere experiment)
3.5.4 Field inside/around loop or solenoid
3.5.5 Repelling force: solenoid and magnet with gravity
3.5.6 Interactions between different coils and magnet
3.5.7 Iron core vertically attracted inside a coil
3.5.8 Attraction/repulsion of two coils
3.5.9 Field in Helmholz coils

3.6 Lorentz Force

3.6.1 Magnetic force on a wire (Pohl experiment)
3.6.2 Turning coil between magnets
3.6.3 Rotating coil motor (paperclip motor)
3.6.4 Homopolar motor, rotating wire (one loop motor)
3.6.5 Homopolar motor, rotating magnet
3.6.6 Reverse generator – simple electrical motor
3.6.7 Faraday motor

Short descriptions of LTK experiments

This section presents short descriptions of a majority of the LTK experiments. Each description consists of a number of main components.

Learning objectives and set-up

Learning objectives and details/pictures of each described experiment helps teachers and students preparing and carrying out the activity.

Activity description

Proposed activities to be performed with the LTK materials.

Minds-on questions

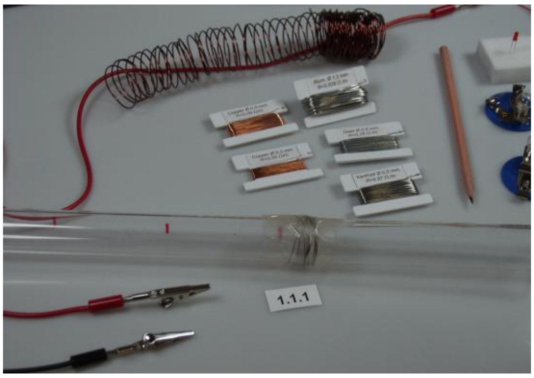
The list of Minds-on questions emphasizes the intended use of LTK materials.

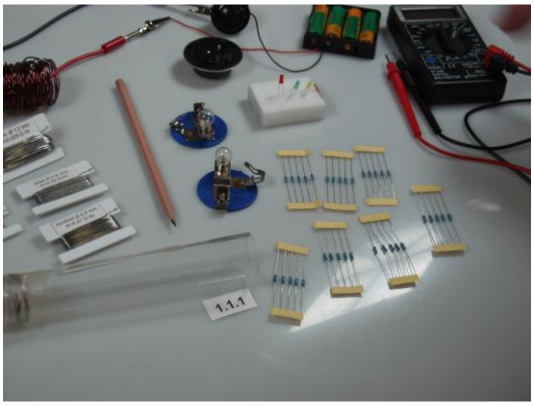
Comments to LTK materials and activity description

Some initial comments are listed at the end of several descriptions. If you have additional comments please join the discussion at http://forum.mosem.eu!

1.1 Conduction in solids, liquids and gases

1.1.1 Conduction in wires





Learning objectives

L 1 - Registering the linear relationship between current and voltage as expressed in Ohm's law.
L 2 - Discovering that the resistance is a property of the material.
L 3 - Discovering that there is a linear relationship between the resistance and the cable length.

Setup

Equipment from the kit: A1/H1 + H5-H7/I + K5-K11 + W2/W4/W9/W10/M + W1, W12-W16 + N3/W11 + V32/H3 + K1,K2,K3,K4 + D/T1

We uncoiled a resistance wire across the large plexiglass plate which is mounted as a table. The power source, 4 AA batteries, were connected to the end points of the wire, A and B. We may expect that the power is constant during the measurement period. The resistance of the wire is unknown and may be measured with the Ohm meter but we have not done such measurements.

We have assumed that we only have one multimeter available so that we can measure the voltage only. In this experiment we have chosen the measurement of the voltage along the wire as a function of the distance from the left connection point A. The location of the right connection point C was fixed by connecting a crocodile clip to this point. We placed the ruler along the wire to know how far point C is from point A.

In principle we may measure the current before measuring the voltage, but since ammeter has an internal resistance, the current in the circuit may be different with and without ammeter connected.

Activity description

In this experiment we use a resistance wire uncoiled across the plexiglass plate, between points A and B (see figure), with a constant current flowing through the wire. A voltmeter is connected between points A and C, which can be moved along the wire.
Ohm's law says: $U = R * I$

Since we can assume that the current is constant, the resistance of the wire between A and C should be proportional to the voltage measured between the same points.
Do the voltage measurements as a function of the distance between the measuring points C and A in mm.

Present voltage as a function of wire length between points A and C.

Minds-on questions

- What determines the current in the wire (the circuit) when we connect the battery?
- What is the relationship between the voltage along the wire and the current, assuming the same material, thickness and length of the wire?
- Will the current in the circuit increase or decrease when the length of wire increases?
- Basing on the measurements, you can suggest how to make a variable resistor.

Evaluation of LTK materials and activity description

One assumes in this activity that he has only a multimeter and a non-ideal voltage source. Alternatively, the multimeter is connected to an amperemeter in order to measure the current.

1.1.5 Microscopic model of conduction in solids

Learning objectives

L 1 - Recognize the particle model for matter with elementary particles.
L 2 - Identify different elements and isotopes based on atomic numbers and number of neutrons.
L 3 - Use the Bohr atom model to visualize the tightly and loosely bound electrons of a single atom that can become valence electrons in a lattice.
L 4 - Recognize and differentiate between atoms and ions for conduction in liquids.

Setup

Equipment from the kit: V21.
Use the Atom model.

Activity description

Use the markers for protons, neutrons and electrons to work with the learning objectives.

Minds-on questions

- What is the purpose of the rings on the plastic boxes in the atom model, and what do they symbolise?
- What are the names, roles, placements and charges of the different pieces in the atom model?
- What happens when you add or remove a proton?
- What happens when you add or remove a neutron?
- What happens when you add or remove an electron?
- Use the model to show the difference between solids, liquids and gases (and plasmas, if in curriculum).

2.2 Moving magnet

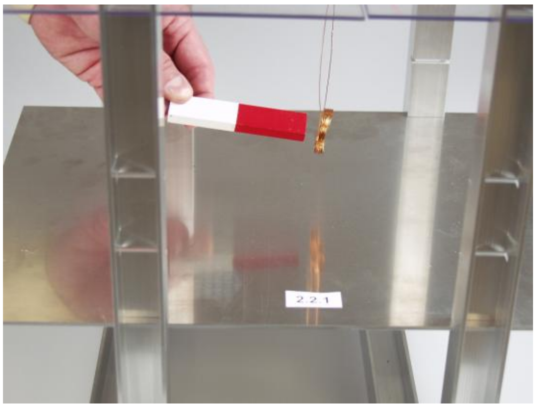
2.2.1 Stationary solenoid, moving magnet

Learning objectives

L 1 - An induced current is produced in the solenoid by the changing magnetic flux passing through the solenoid.
L 2 - The induced current is produced by an induced Electromotive Force (EMF).
L 3 – The induced EMF depends on the rate of the flux.
L 4 - The sign of the induced current depends on the sign of the change in the magnetic flux.

Setup

Equipment from the kit:
V18, X2, X5 + X9, X10, X11, X12 + W2/W4/W9/W10/M + V32
The solenoid is connected with the multimeter. The magnet is brought closer to the solenoid and then moved away from it. The two signals have opposite signs.



Activity description

The magnet and the solenoids of different sizes (diameter, number of coils, density of coils) are on the table. The solenoid is connected with the multimeter. No battery is included in the closed circuit so the multimeter signal is zero. The challenge is to produce a signal in the tester, as intensive as possible.
The signal appears in the tester display (or the pointer moves in the case of an analog tester) when we move the magnet near the solenoid, bring the magnet closer to the solenoid, pass the magnet transversally or rotate the magnet near the solenoid. An induced electric current is produced in the solenoid.

- When the speed of the magnet increases/decreases, the current peak value increases/decreases.
- When the area of the solenoid changes, the current peak value changes.
- When the direction (the sign of the velocity) of the magnet movement changes, or the pole facing the solenoid changes, the signal sign changes.

An induced current is produced in the solenoid by changing the magnetic flux in the solenoid. This current is produced by an induced EMF. The intensity of the induced EMF depends on the rate of this change. The sign of the induced EMF changes when the direction of the magnetic flux changes.

Minds-on questions

- Act on the magnet to produce a signal in the tester. What kind of actions generate induced current in the solenoid? When the current peak is stronger? Is the induced current sign always the same? How can you change it?
- The induced currents are related to changes in time. What kind of physical quantity can be introduced to synthesize these changes? How the change of this quantity in time is related to the induced effect?

2.2.2 Oscillating magnet in a coil

Learning objectives

L 1 - Recognize the induced effects when the magnet is oscillating near the coil.
L 2 - The signal frequency is the same as for the oscillator when the magnet does not cross the coil (is double of it when the magnet crosses the coil).
L 3 - The induced current is produced by an alternating EMF generated by the variation in time of the magnetic flux.

Setup

Equipment from the kit:
X2,X5,J1,W8 + X10,X11,X12,V29,V30,V31 + W2/W4/W9/W10/M + V32,K1,K2,K3,K4 + D/T1

A magnet is suspended at the end of a vertical spring (the spring is hanging on a vertical support). At rest the magnet is few centimeters over a coil (or put inside it, if the diameter of the magnet is less than the internal diameter of the coil).
In the pictures we can see different magnets oscillating in different coils. To obtain a low frequency oscillator, we put a brass cylinder between the spring and the magnet. In this condition the time response of the multimeter does not affect the observation.
A forced magnet-mass-spring system is obtained taking in the hand the free end of the spring and oscillating the hand in phase with the oscillator, in a similar way of the yo-yo toy.

Activity description

A spring is hanging on a vertical support. A magnet is suspended at the free end of the spring. When the magnet is at rest the tester signal is zero. When the magnet is oscillating, almost reaching or reaching the coil or entering it, a tester signal appears. The signal is positive (negative) when the magnet goes closer to the coil. It becomes negative (positive) when the magnet goes away from the coil. The sign of the signal depends on the magnetic pole facing the coil and it changes when the distance between the magnet and the coil reaches minimum or maximum.
The signal is an alternating induced current produced by the induced EMF. The EMF is caused by the change in time of the magnetic flux in the coil with the same frequency as the oscillator frequency (when the magnet remains always outside the coil). So the alternating current frequency and the oscillator frequency are the same. The sign changes according to Lenz's law.

Minds-on questions

- The magnet-spring system is oscillating in the coil that is connected with the multimeter. What do you observe on the tester display? Is the sign of the signal always the same? How is the frequency of the signal sign changing? Compare the frequency of the signal and the frequency of the oscillator. Are they equal? Explain it.
- Why does the change in the signal sign occur when the magnet is at the minimum distance from the coil?
- Rotate the magnet poles 180°. What will change in the description of the phenomena? Explain it.
- The induced electric current flowing through the coil produces a magnetic field. Indicate the direction of the current and the direction of the induced magnetic field. Compare the direction of the induced magnetic field and the direction of the magnetic field produced by the magnet. Are they always the same? Explain the observations and summarize them in a general law.

2.2.3 Magnet falling through a coil

Learning objectives

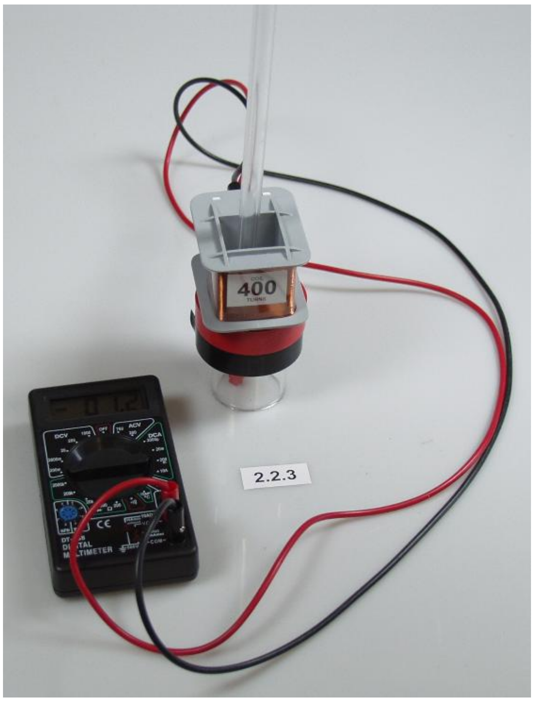
L 1 - Recognize the signal of an impulsive induced current, due to an induced EMF caused by a magnetic flux change in time, from an initial value (lower or approximately zero when the magnet is in the initial position) to a final one (when the magnet cross the coil).

L 2 - The rate of this change is related to the speed of the magnet. It also depends on the characteristics of coil and magnet.

L 3 - The sign of the induced EMF changes according to Lenz's law.

Setup

Equipment from the kit:
X2 + V6 + X10, X11, X12 + W2/W4/W9/W10/M + V32,K1,K2,K3,K4 + D/T1



Different coils and magnets are put on the table. The coil is connected with the multimeter. A magnet falls down starting from 10-20 cm over the coil. When the magnet passes through the coil, a signal in the tester is observed. The signal intensity changes when the initial height of the magnet over the coil is changed or other coils are used. The sign of the signal changes when the magnet pole initially facing the coil is changed.

An observable signal is obtained when the initial position of the magnet is less than 20-25 cm. The response time of the tester does not permit to observe signal when the free falling magnet is too fast. The opportunity to show the EMF sign change, when the magnet pole initially facing the coil is changed, is also limited.

Activity description

A magnet falls down passing through a coil connected with the multimeter. The multimeter shows an impulsive signal. The intensity of the signal increases when we increase the initial position of the magnet. The sign of the signal depends on the magnet pole initially facing the coil.

The signal changes when we use coils of different characteristics (i.e.: coil diameter, number of loops, wire diameter) or different magnets. The signal intensity is related to the characteristics of the coil and the magnet.

The signal observed on the tester is an impulsive induced current. The induced current is due to the induced EMF caused by the magnetic flux change in time, from an initial value (lower or approximately zero when the magnet is in its initial position) to a final one (when the magnet crosses the coil). This change is related to the initial position of the magnet, which determines the speed of the magnet when it crosses the coil. It depends also on the characteristics of the coil and the magnet because these characteristics determine the influence of the magnetic flux on the coil.

Finally, when the pole facing the coil changes, the sign of the induced EMF changes as well, according to Lenz's law.

Minds-on questions

- Place the magnet over the coil and let it fall down through the coil. What do you observe on the display of the tester? First describe and then explain.
- Is the sign of the signal always the same? Make a prevision, try, describe, compare the predicted and the experimental results, explain.
- When is the signal stronger? Make a prevision, try, describe, compare the predicted and the experimental results, explain.
- Do the results of the experiment depend on the initial condition of the magnet? Make a prevision, try, describe, compare the predicted and the experimental results, explain.

2.3 Eddy currents

2.3.1 Lazy pendulum

Learning objectives

L 1 - Observe how the induced eddy currents slow the pendulum.
L 2 - Explain how the lazy pendulum works.

Setup

Equipment from the kit:
X2,X5,J1,W8 + V39,V40,V41
See the picture.

Activity description

Hang the pendulum with a magnet as a bob, so that it can swing about 5 mm over the copper slab. Displace the pendulum from its resting equilibrium position and release it. Observe its movement as it approaches the copper slab. Replace the copper slab by the aluminium slab and look if there is any difference in braking effect.

Minds-on questions

- How do you explain that the pendulum brakes hard when approaching the copper slab?
- Can you observe any difference in the braking effects between the copper slab and the aluminium slab?
- Can you explain a difference in braking effects?

2.3.2 Electromagnetic brake

Learning objectives

L 1 - Observe how the induced eddy currents slow the movement and thus can be used as a brake.
L 2 - Explain how does a magnet brake work.

Setup

Equipment from the kit:
T8/U1/V1 + V13 + T11,T12 + X2,X5,J1,W8
See the picture.

Activity description

Mount the disc on the rod (brass or wooden) attached to the experimental table in a way it can freely rotate. Protect the disk from sliding off, so that the brass rod can be used as a "drive shaft".

Hold a magnet near the outer edge of the disk without touching it.

Repeat the experiment, now with the aluminium disk with the slots.

Minds-on questions

- Can you observe any difference in braking power for the discs with and without slots?
- Can you explain the difference in braking power?

Evaluation of LTK materials and activity description

There is a little difference in the braking effect between the disks with and without slots. For the disc to rotate in a stable way, it is important to use pads. The pads are pressed to the disk by using two small plastic tubes that fit tightly to the brass rod. In this experiment bits of pipettes were used.

2.3.3 Magnetic slalom

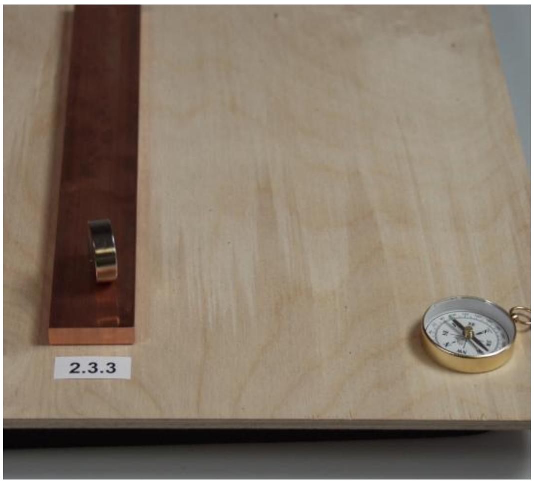
Learning objectives

L 1 - Describing the movement of the magnet rolling down the copper plane.
L 2 - Explaining the movement using Lenz's law and eddy currents.

Setup

Equipment from the kit:
X5 + V39,V40 + T1/V41

A strong magnet is rolling on a inclined copper plane. If the magnet starts from the center of the higher endpoint, the trajectory of the magnet is a straight line, but the velocity of the magnet decreases. If the magnet starts from the left or right side of the endpoint, it moves along a curve if it were drunk.



Minds-on questions

- What happens if you change the angle of the inclined plane?
- What do you think: Is there any influence of the magnetic field of the Earth on the magnet movement?
- Does the movement change if you change the orientation of the copper plate?
- Does the movement change if you change the orientation of the magnet before rolling it down?
- Try to move the magnet quickly back and forth near the plate. What will happen?

2.3.4 Sliding magnet

Learning objectives

L 1 - Describing the movement of the magnet sliding down the copper plane

L 2 - Explaining the movement using Lenz's law and eddy currents

Setup

Equipment from the kit:

X5 + V39,V40

Minds-on questions

- What happens if you change the angle of the copper plane?
- What do you think: Will there be a difference if you turn the magnet to the other side (change the poles)?

- What will happen if you use different magnets (stronger, bigger…)?
- How does the movement depend on the shape of the magnet? Try the experiment with other shapes, e.g. a bar magnet!

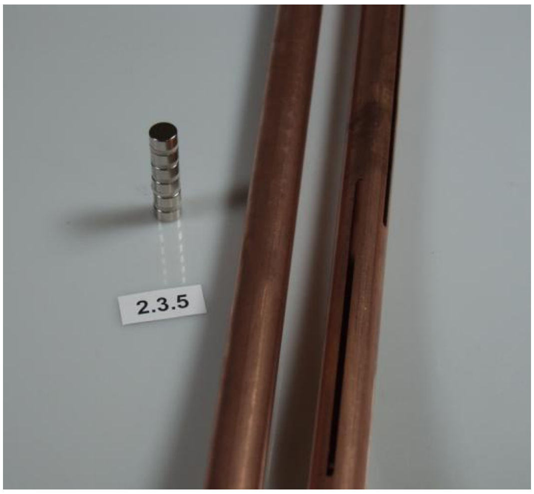
2.3.5 Magnet falling down copper tubes

Learning objectives

L 1 - Describing the movement of the magnet falling through copper tubes.
L 2 - Explaining the movement using Lenz's law and eddy currents.
L 3 – Discussing differences when using other falling objects.

Setup

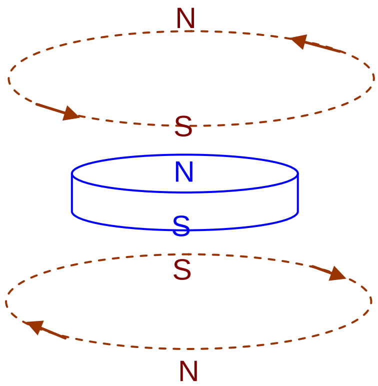
Equipment from the kit:
X2 + V10,V14 + T1



When a neodymium magnet is dropped through a vertical copper pipe (without the slits), it falls much slower than a metal peace. The rate of fall quickly reaches a terminal velocity and it takes about 20 seconds to fall out of the other end of the 0.5 m long tube in our set-up.
This is because the copper tube "sees" a changing magnetic field from the falling magnet. This changing magnetic field induces an eddy currents in the copper tube according to Lentz's law. The induced current in the copper tube creates its own magnetic field that opposes the magnetic field that created it.
Repeat the experiment with the tube with the slits. What do you observe?

Minds-on questions

- What happens if you change the angle of the copper tube?
- Some times the magnet overturns while moving through the tube. Why?
- What changes do you expect if you use the different diameter pipes?



2.3.6 Stack of magnets falling down copper tubes

Learning objectives

L 1 - Describing the movement of magnets falling down copper tubes.
L 2 - Explaining the movement using Lenz's law and eddy currents.
L 3 – Measuring fall times of magnet stacks.
L 4 - Discussing the results.

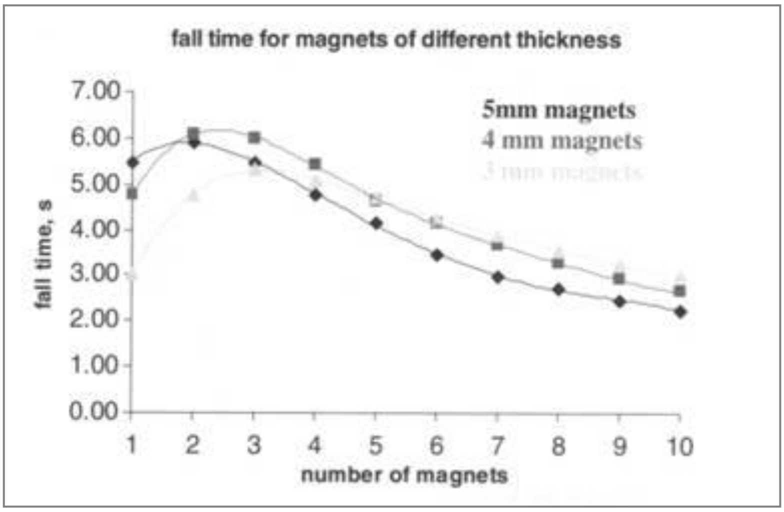
Setup

Equipment from the kit:
X2 + V9,V11,V14 + T1
The setup is similar to 2.3.5.

You should start with one magnet and measure the fall time. Add magnets, one by one, and compare the times. Try to make a diagram time vs. number of magnets!

Minds-on questions

- ➢ What do you think will happen if you use longer magnets instead of stacks?
- ➢ What changes do you expect if you use tubes with other diameters?



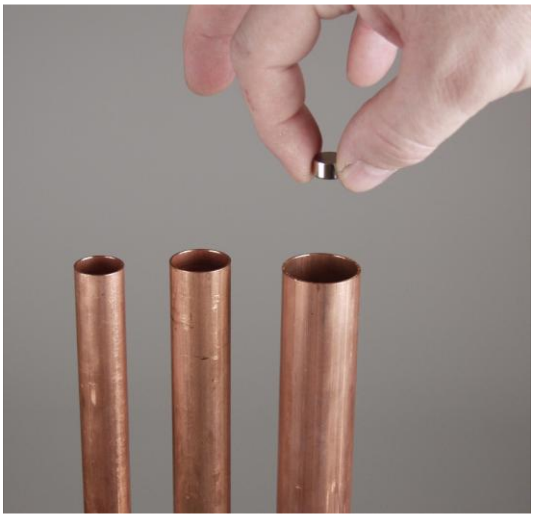
Source: Ireson G., Twidle J.: Magnetic braking revisited. In: Eur. J. Phys. 29 (2008) 745 – 781 (measurement with 10 magnets)

2.3.7 Magnets falling down different tubes

Learning objectives

L 1 - Describing the movement of magnets falling down different tubes
L 2 - Explaining the movement using Lenz's law and eddy currents

Setup



Equipment from the kit:
X1,X2 + V6,V7,V9,V11,V14 + T1
The setup is similar to 2.3.5.

A strong magnet is falling down a copper tube. Now use also other tubes: plastic, copper with slits and others if you have, and compare the results.

Minds-on questions

- What do you think will happen if you could make more or larger slits?
- Think about other tube materials: What would you observe using iron?
- Try the experiment with tubes of tin foil. What do you expect?

2.3.8 Magnet falling on copper/aluminium bar

Learning objectives

L 1 - Describing the movement of the magnet falling on a copper bar.
L 2 - Explaining the movement using Lenz's law and eddy currents.

Setup

Equipment from the kit:
X2,X5 + V39,V40,V41

A strong magnet falls from a height of several centimeters on a thick bar of copper or aluminium.

Minds-on questions

- What is the difference between dropping the magnet on copper and on aluminium?
- What happens if you take two copper bars?
- What do you think: Is there any influence of the magnetic field of the Earth? Does the movement change if you turn the magnet?

2.3.9 Chaotic pendulum

Learning objectives

L 1 – Observation of the unstable motion when a magnet swings back and forth over a collection of magnets.

Setup

Equipment from the kit: X2 + E5,J1,X4 + U1,T1,V1,V13

Activity description

Put five out of the six small, cylindrical magnets on the plate as close as possible but without sticking them together. Use a little "school chewing gum" to attach them to the plate so that they do not "run away". You can also use the small rod magnets. Hang the pendulum from the experiment table so that it can swing about 8-10 cm above the table with magnets. Displace the pendulum from its resting position and release it. Observe its movement over the collection of magnets.

Minds-on questions

- How would you describe the motion of the pendulum?
- Can you give a rough explanation of why this happens?

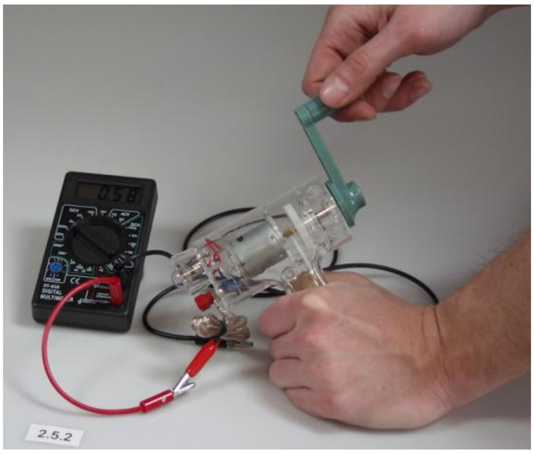
2.5 Applications

2.5.2 Generator

Learning objectives

L 1 - Improve understanding of the Faraday-Newman-Lenz law

L 2 - Improve understanding of the conversion of the electrical energy into the mechanical one



Setup

Equipment from the kit:
V20 + H4/W2/W4/W9/W10/M + V32.

Activity description

Hold the generator, with the lamp properly placed in its socket, with your one hand and turn the crank with the other one. Repeat the experiment while the lamp has been removed.

Before doing anything, ask the question “do you expect that your muscular effort will be the same when you turn the crank with and without placing the lamp in its socket?”

Let the students first realize the experiment and let them report about their feelings. Then ask them “what do you think is happening?”

Minds-on questions

- Do you need some energy to make a lamp light up?
- Can the lamp light be related to your muscular effort?
- Can you describe in detail and in the correct sequence the physics processes involved and in particular those linked to energy transformation?

3.1 Magnetic poles

3.1.1 Exploring magnetic field and field lines

Learning objectives

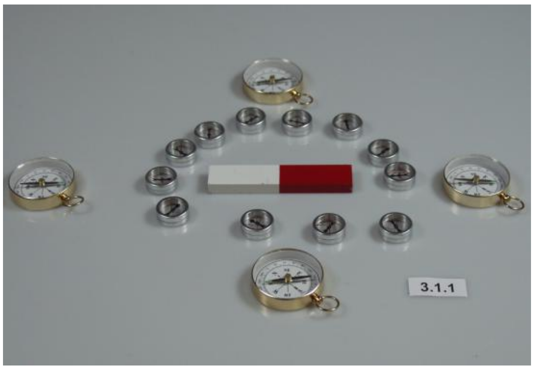
L 1 - The compass needles, far from other magnets, indicate the same direction, the direction of the earth's magnetic poles.

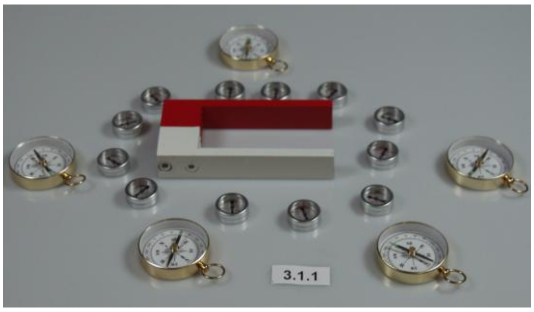
L 2 - The presence of a magnet modifies the orientations of the needles. They are tangent to lines that:

- come out from one pole and go into the other one,
- are symmetrical to the N-S axis of the magnet.

Setup

Equipment from the kit: V18, V23, X2, + B, G
See the pictures.





Activity description

Put some needles on a table, far from other magnets and sufficiently far from each other (so that they don't influence each other): they all have the same orientation, align themselves with Earth's magnetic field. Bring a magnet near the needles: their orientation changes when the position of the magnet changes. Put the magnet on a piece of plexiglass and note the direction of the needles in different positions and draw the lines tangent to those directions (field lines). They form a symmetric configuration to the axis of the magnet.

Minds-on questions

- What determines the needle orientation?
- What does the needle interact with?
- We say that a needle is an explorer: what does it mean? What is it explorer of?
- What does the configuration of the directions of the needles represent?
- Are the directions of the needles sufficient to indicate the lines of the magnetic field that orients the needles?
- How the configuration of the directions observed in horizontal plane will change if we consider inclined or vertical planes?

3.1.2 Magnetic sticks and balls

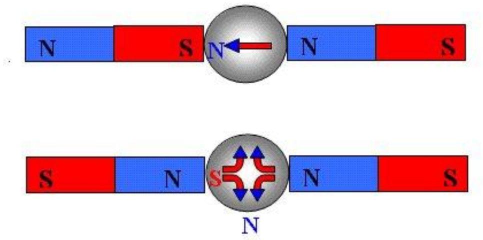
Learning objectives

L 1 - Magnets have two poles. If a steel ball is put between two magnetic bars, we always observe attraction, independently of poles setting.

L 2 - This effect is due to the reorganization of magnetic domains inside the ball.

Setup

Equipment from the kit:
X1 + F
See the picture



Activity description

Put a little still ball on the table and bring a magnet near, each time facing a different pole. There is always attraction, independently of faced poles.
Put the steel ball between two magnetic bars: it plays the role of connector between the magnets, independently of faced poles.
It is possible to create wonderful buildings with magnetic bars, putting ferromagnetic spheres between the magnets.
This effect is due to the reorganization of magnetic domains inside the sphere: in the case of the opposite poles attached to the sphere it becomes a magnetic dipole with the axis oriented along the magnets; in the case of the same poles attached to the sphere it "adapts" its poles so that it is attracted by both magnets. "Lost" poles are on the plane perpendicular to the axis of the magnets.

Minds-on questions

- To which kind of magnetics do you classify the spheres?
- Objects made of ferromagnetic materials are considered temporary magnets: how do you explain this fact?
- How can you draw the poles distribution in the sphere if you attach two other magnets with the same polarities as the previous ones and perpendicularly to them?

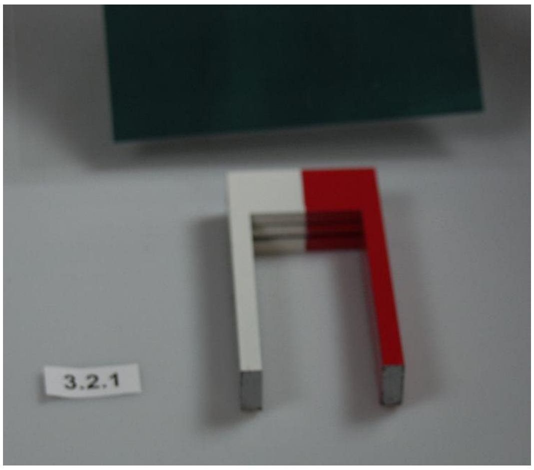
3.2 Magnetic materials

3.2.1 Iron filings and flux detector

Learning objectives

L 1 - Visualization of the magnetic field with the aid of iron filings and flux detector.

L 2 - Introduction of the concept of magnetic field lines.



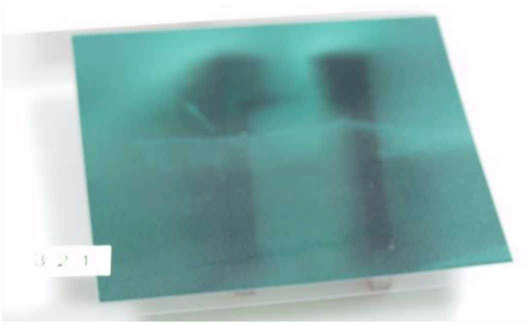
Setup

Equipment from the kit:

T7/T8/U1/V1 + A4 paper + V18, V23, X1, X2, X5 + V33 + T4.

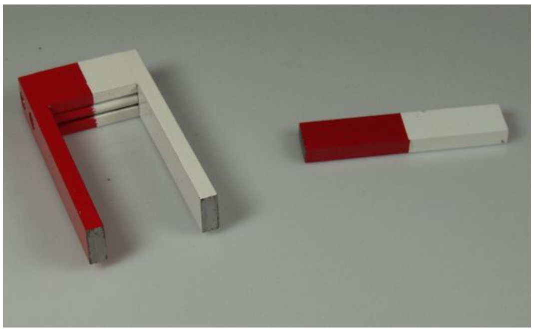
Activity description

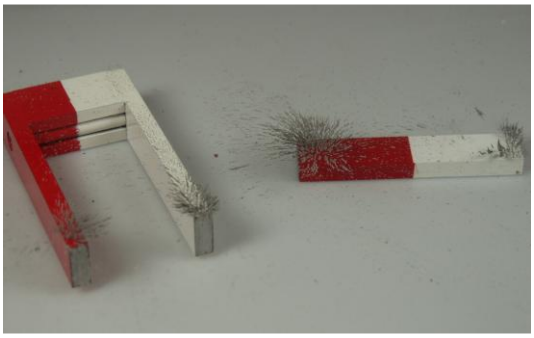
Place the flux detector or a sheet of plexiglass, with iron filings spread on it, above magnets of different shapes. Observe changes in colour of the flux detector or, gently hitting a plexiglass, allow the iron filings to locate in the direction of magnetic field lines.



Minds-on questions

- What is a flux detector made of?
- Does the way iron filings are located above magnets depend on their shapes?
- Which kind of information about the magnetic field can be obtained in such investigations?





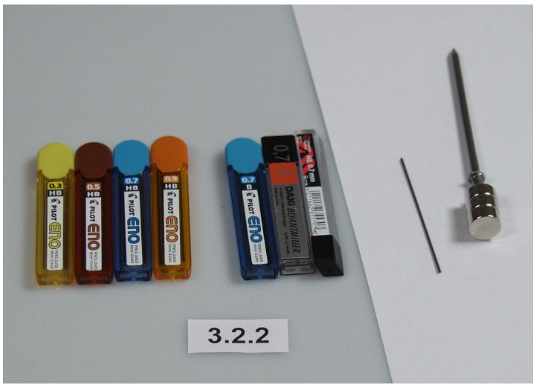
3.2.2 Pencil stick exploration

Learning objectives

L 1 - Observe interaction between a strong magnet and a pencil graphite.
L 2 - Investigate magnetic properties of a graphite.
L 3 - Learn how to distinguish diamagnetic substance.

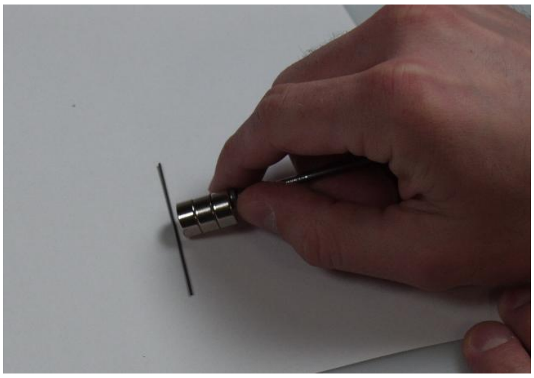
Setup

Equipment from the kit:
T7/T8/U1/V1 + A4 paper + X2/X5/J1/W8 + J3-J9
Put a pencil graphite on a smooth surface. Take a strong magnet out of the box - be aware when using a strong magnet.



Activity description

1. Come slowly with the strong magnet to pencil graphite, perpendicularly to its length.
2. Observe behaviour of a pencil graphite.
3. Does the pencil graphite still remain static when a magnet is approaching it?



Minds-on questions

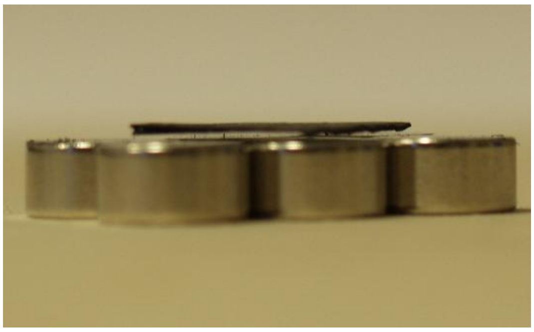
- What happens when a strong magnet is being moved towards graphite? Try to explain your observations.
- How we call substances that behave like a pencil graphite?

3.2.3 Pyrolithic graphite levitation

Learning objectives

L 1 - Be able to describe the behaviour of a slice of graphite in a magnetic field.
L 2 - Be able to explain the levitation using the geometry of the field and the diamagnetic.

Setup



Equipment from the kit:
X1/X2 + E1
Cut a thin slice of the pyrolytic graphite, ca. 0.5 cm^2 with a sharp knife. Set six cilindrical magnets of the type X2 in a rectangle, as shown in the figure.
To be sure that the magnetic poles are correctly oriented, you can do the following:

1. Start with a stack of magnets. In such a stack the magnet poles are always aligned in the same direction.
2. Take one magnet at a time an put them over the table in a rectangle as shown in the figure. Be sure to turn the magnets so that they lie with alternating south poles and north poles next to each others.

Activity description

Then you are ready to place the piece of pyrolythic graphite above the magnets.

The levitation becomes even more pronounced if one uses cubic neodymium magnets, as the gaps between the magnets are smaller.

Minds-on questions

- How can you make a graphite lamella float above a strong magnet?
- Why does the lamella float at all?
- What will happen with the graphite above one strong magnet?
- In which way it is similar to the levitation of a superconductor? What is the difference?
- The levitation needs energy, to work against the gravitation of Earth. Where does this energy come from?

Evaluation of LTK materials and activity description

The experiment works well when the magnets are put together in a proper configuration.

3.2.4 Magnetic carousel (H_2O-$CuSO_4$)

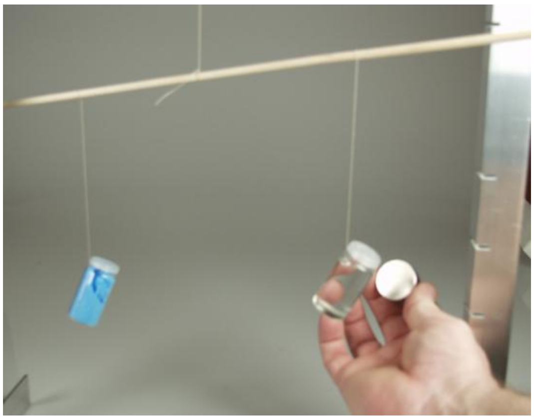
Learning objectives

L 1 - Be able to observe interaction between a strong magnet and water and copper sulphate (CuSO4).

L 2 - Be able to explore the magnetic properties of substances.

L 3 - Be able to understand the difference between diamagnetic and paramagnetic substances.

Setup



Equipment from the kit:
U1/V1/V13 + C1/C2 + E5 + V12 (cut to 36 cm) + X2/X5/J1/W8

Set up the brass rod between the legs of the experimental table. Hang the wooden stick on the rod using a wire hook. The stick should be cut to the length of 36 cm, so that it is free to rotate between the aluminium legs. Hang the two small glasses on the stick - use pieces of wire to make fasteners for the glasses - to make a carousel.

Activity description

When you gain weight balance (it may take a while), get the magnet closer to (about 5 mm) each glass with copper sulphate and water. The magnet will not affect the glasses. Observe what happens to the balance.

Minds-on questions

- What happens when the strong magnet is close to the glass of water?
- What happens when it approaches the glass with copper sulphate?
- Does the balance move differently in these two cases? Can you explain what you observe?
- What are the magnetic properties of substances that behave like water, and those that behave like copper sulphate?
- Is it possible to use such a method to distinguish between diamagnetic and paramagnetic substances?

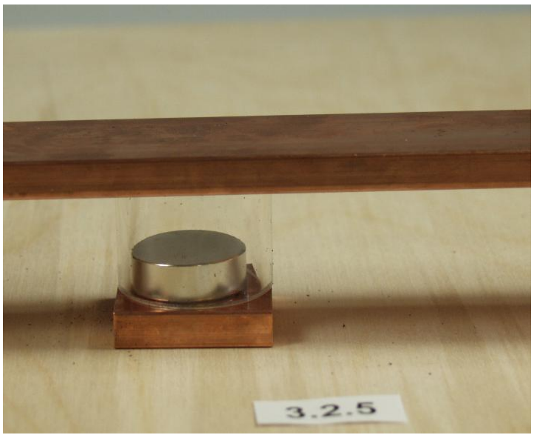
Evaluation of LTK materials and activity description

Add a little insulated wire connector in the case it can be difficult to balance the weights. The effect is clear.

3.2.5 Levitating magnet (Cu-Cu bars with magnet in between)

Learning objectives

L 1 - Be able to explain why the magnet floats.

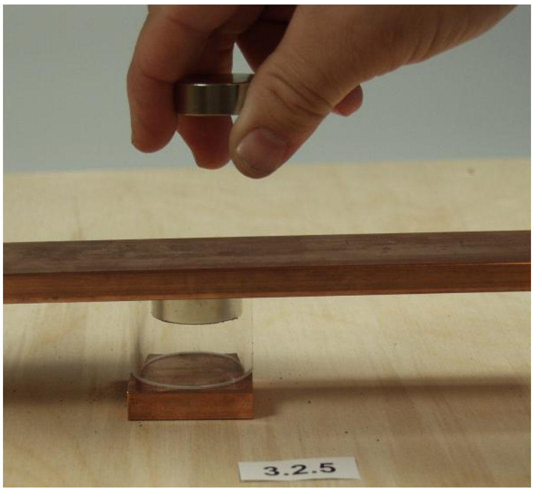


Setup

Equipment from the kit:
V40 + V41 + V2 + X5
Place one strong magnet on the small copper bar. Put the plexiglass tube on the magnet and put the large copper slab on the top of the plexiglass tube. Hold the other magnet in your.

Activity description

Move your hand slowly toward the large copper bar and the magnet in the plexiglass tube.
Eventually the magnet in the pipe will levitate.



Minds on questions

- Why is it so difficult to get the magnet to remain levitating?
- How can you achieve a stable levitation?
- Try the aluminium bar. Do you notice any differences?
- What is the role of the bottom bar? Try removing it.

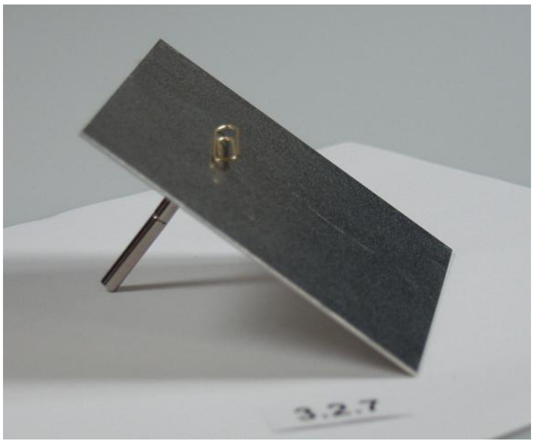
Evaluation of LTK materials and activity description

The experiment works very well.

3.2.7 Magnetic shielding

Learning objectives

L 1 - Investigate behaviour of different metals when placed between source of magnetic field and ferromagnetic object
L 2 - Study concepts of magnetic shielding and permeability.

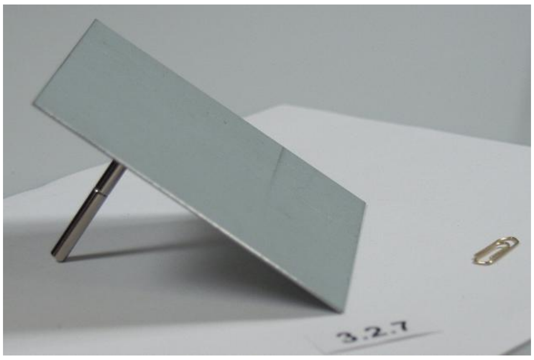


Setup

Equipment from the kit:
X2, X5 + T5, V37, V38 + B, G.

Activity description

Place strong magnets beneath pieces of different metals from the kit to make incline plane. Try to attach a paper clip as shown in the pictures.



Minds-on questions

- What are the possible explanations of different behaviour of a paper clip?
- Which physical properties of a metal are causing observable effect?

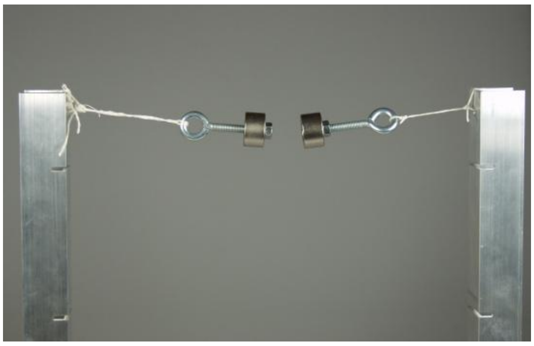
3.3 Permanent magnets

3.3.1 Magnetic dog

Learning objectives

L 1 - Observe interactions between two strong magnets
L 2 - Observe interaction between a magnet and a steel ferromagnetic clip
L 3 - Understanding the difference between the poles of magnets.

Setup



Equipment from the kit:
U1/V1 + E5 + X4/J2 + E3,E4 (+ T5,V37,V38) + T6. Be aware when using strong magnets.
The figure shows how a strong magnet (or a paper clip instead of the magnet) can be suspended.

Mount the eyescrews on the two ring magnets, so that the depression with the nut is pointing away from the eye. Hang the magnets between the legs of the experimental table as shown in the picture.

Alternative setup

Mount the eyescrew on the one ring magnet as previously. Instead of the second magnet use the paper clip attached to the second eyescrew. If the magnet is a solid cylinder (and thus the eyescrew can not be mounted on it) it may be put into the plastic bag which should be tied the table leg.

Activity description

First, come with a strong magnet near the other magnet. Investigate interaction. Try to set-up the static situation shown in the picture. Repeat the experiment using a paper clip instead of a magnet. Repeat investigation with a paper clip.

Minds-on questions

- What happens when two strong magnets approach each other?
- What happens if you insert an aluminium plate between the magnet and the paper clip?
- What happens if you do the same with a steel plate? Note.
- Do magnets and paper clips behave in the same way? How do we call substances that behave as the paper clip?
- Explain your observation?
- Can you describe a method for shielding the magnets from the ferromagnetic materials?

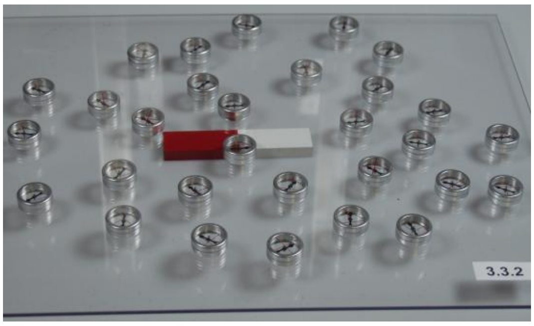
Evaluation of LTK materials and activity description

Important to be aware that the ring magnets X4 comes in pairs.
Drill several holes along the legs of the experimental table in order to be able to put the brass rods in different heights.
Use couple of wooden clothes peg to keep things in place, eg. the wire, to which the paper clip is attached. Crocodile clips can be difficult to be used for this purpose.

3.3.2 Magnetic field with filings/small compasses

Learning objectives

L 1 - Be able to form a picture of the magnetic field in space around the magnets of different shape



Setup

Equipment from the kit:
T7/T8/T9/U1/V1 + V18, X1, X2, X5, X6 + V33 (+A4 paper), G
We have previously explored the magnetic field using small compasses. In this experiment we will use two other aids:
• Iron filings
• Magnetic flux detector

Activity description

Put a cylindrical magnet on a flat surface and put the plexiglass over the magnet. Sprinkle iron filings on the plate, where the magnet is located, just enough to see the structure of the field lines.

The iron filings can be easily collected in a coffee filter and placed back into the box.
Be sure to keep other magnets far away from the iron filings. It's very hard to remove filings which have already attached themselves to the magnet.

The magnetic flux detector shows only the flux density but no field lines. Dark areas indicate a high flux density, lighter areas a lower flux density. Studying an image we can however see that this is not necessarily correct. Note the lighter areas in the corners, where one would expect particularly strong field.

Repeat the experiment with magnets of different shape and strength.

A magnetic ball is not a form that clearly shows where the poles are. Using the flux detector one can see the poles distinctly.

Minds-on questions

- Why do both the magnetic compass pointer and the iron filings indicate the field lines?
- A compass pointer shows the direction of the magnetic field along the field lines. What about the iron filings?
- What is the geometric relationship between the field lines and the magnet?
- Can the lines that emerge with the help of iron filings represent the direction of the forces that occur in the field?
- Are the field lines only in the plexiglass plane or spread themselves out, across the room?
- What happens to the field lines between two magnets
  - Which repel each other?
  - Which attract each other?

Proposal for further investigation

1. In which way would steel wool cut into small pieces serve as a substitute for regular iron filings?

2. Construction of a field line indicator:
Cut a tin and fold the sheets in a rectangle. Cut the small needles and fix them, in equal distances, on a wooden board using small tacks or brass pins. Add a bead on the top and bottom of each compass needle so that it can rotates easily. Put the needles on a plexiglass plate. Put a magnet on the plexiglass plate and look what happens with compass needles.
If we put a small compass near a magnet, we will see that its needle turns itself in a certain direction. If we move compass to different places, we will see that the needle changes direction. Compass needles behave like little magnets affected by the magnetic forces from the big magnet. The direction of the magnetic needles shows the direction of the forces. We can draw arrows and lines showing the direction of this force in various locations near the magnet. The lines are a "picture" of the magnetic force field around a magnet.

Evaluation of LTK materials and activity description

Add a couple of coffee filters and a small soft brush into the suitcase. These are the practical utilities to collect iron filings.
Consider choosing the iron filings with elongated grains if they exist - they will probably give a better picture of the field lines.

3.3.4 Magnets floating on the water

Learning objectives

L 1 - Two magnets floating on the water are free to rotate and both rotate to find the configuration of equilibrium. Two magnets interact in the same way and the different behaviour depends only on how they are set up.
L 2 - Interactions between two magnets free to rotate show the existence of two different magnetic poles N-S that give:
- Attraction between opposite poles (N-S) independently of the direction of the movement or the magnet that moves
- Rotation to go in configuration (N-S) of attraction between the same poles (N-N o S-S)

Setup

Equipment from the kit:
X1 + D + bowl with water
See the picture.

Activity description

Let the two identical magnets, fixed to polystyrene rafts, can float on water. Bring one raft slowly nearer to the other one. You can see that opposite poles attract each other or, being in other configurations, they rotate so that the opposite poles could come together.

Minds-on questions

- Let's compare the interactions between magnetic poles and electric charges: are they similar?
- Which differences are important?
- Are the interactions reciprocal?
- How can a magnet know that the other one is closer and closer?
- How can you explain what you observe?

3.3.6 Repelling force: measurement with gravity

Learning objectives

L 1 - Observation of the repulsive forces between like magnetic poles

L 2 - Measurement of the repulsive forces between like magnetic poles.

Setup

Equipment from the kit:

V7 + X1 + T6

T6 1 pc. ruler 50 cm

V7 1 pc. pleksiglass tube

X1 12 pcs. small rod magnets

1 pc. small wooden plug cut from the long wooden rods

1 pc. scale for the weighing of rod magnets

Close the end of the tube (V7) with the wooden plug so that the magnets could not fall out. The mass of each of small magnets is 3.7 g, experiencing a gravitational force of 36.3 mN.

Activity description

In this task, we shall determine the repulsive force between two equal poles as a function of the distance between the magnets.

1. Drop a first magnet down the pipeline so that it lies at the bottom. Hold the tube vertically.
2. Slip a second magnet down the tube, so that the like poles meet. There will be some distance between the magnets because of the repulsive force between them. The force that pushes the magnets from each other is equal to the weight of the rod magnet (Newton's 3rd law).
3. Measure the distance between the magnets.
4. Drop a third magnet down the tube. This doubles the weight of the magnets and diminishes the distance to the first one. Read the distance and note the weight of the two magnets.
5. Repeat this with as many magnets as possible.
6. Save the results in a table and then draw a curve showing the repulsive force as a function of the distance between the magnets. Present the relationship between the repulsive force and distance.

Minds-on questions

- What is the reason that magnets repel each other?
- How can we find a correlation between the repulsive force of two magnets and the distance between them?
- What assumptions should underlie the proposed measurement method to give correct results?
- Does it matter if the third and next magnets are attracted or repelled by each other?

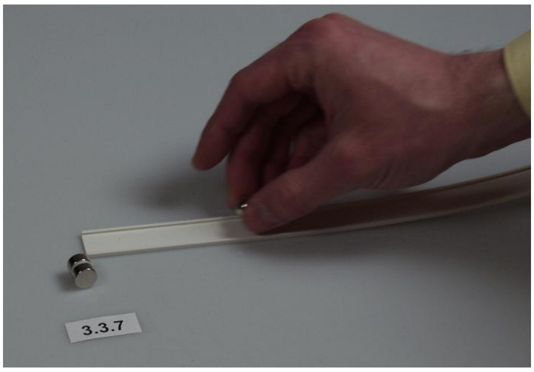
3.3.7 “Ski jumping” in a magnetic field

Learning objectives

L 1 - Recognizing that the ball will become magnetized as a result of the magnetic field of the permanent magnet.

L 2 - Recognizing that the magnetic interaction is strongly distance dependent: it is only effective at short range and vanishes elsewhere.

L 3 - Recognizing the experiment as a demonstration of scattering from a central potential and investigate the relation between the impact parameter and the scattering angle.



Setup

Equipment from the kit:
V15 + F + V18, X2, X5 + T6.

Activity description

An inclined plastic profile is placed on a smooth table. A permanent magnet is fixed to the table near the end of the profile. An iron (steel) ball is released from the top of the profile and is rolling down.

When the ball passes the permanent magnet, it interacts with the magnet, its motion trajectory is deflected and its velocity changes.

Minds-on questions

- How does the ball interact with the magnet when passing it? Describe the trajectory of the ball’s motion.
- What happens to the non-magnetized iron ball (ferromagnetic object) when it comes in the neighbourhood of the permanent magnet?
- How the magnetic interaction between the ball and the magnet depend on the distance between these two?
- What is the relation between the impact parameter b and the deflection angle?

3.3.11 Interaction between two magnets

Learning objectives

L 1 - Interaction between two magnets allows the recognition of poles: there is attraction between opposite poles and rotation of like poles followed by the attraction between the turned poles. You can observe this fact bringing the magnet, held in your hand, near to another one (opposite or like) put on the table or suspended.

L 2 – Getting closer to each other, without rotation, of the opposite poles is possible only if both magnets are arranged along a straight line.

L 3 - Compass needle behaviour is similar to that of a suspended magnet: so we consider it as an explorer.

Setup

Equipment from the kit:
X1 + B.

Activity description

Bring a cylindrical magnet near to another one, put on a table. They approach each other and join together eventually. Invert the disposition on the table. Repeat the experiment: the magnet on the table rotates and attaches to the second one.

Repeat the same experiment with opposite pole of the magnet held in your hand. The behaviours are always as the two described above. So you can individualize two poles in each magnet - mark the poles that caused the rotation with red colour.

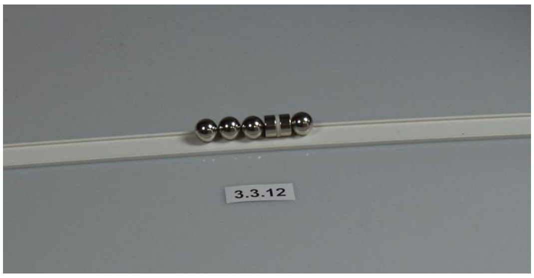
Suspend a magnet and check that it moves and joins with the other one getting closer to it when facing poles are opposite, while it rotates when facing poles are like and then the turned poles attract.

Bring the magnet near a compass and observe that the compass needle rotates to face one end of the magnet in one case, while it positions itself along the axis of the magnet, in the other one. You recognize that compass needle behaves in the same way as the magnet and so it is a magnet...

Minds-on questions

- How many kinds of behaviours do two magnets manifest?
- How can you proof that poles are always and only two?
- How does a magnetic pole interact with middle part of another magnet?
- Considering differently shaped magnets, how can we individualize poles with our explorer magnet or with the compass?

3.3.12 Gauss cannon



Learning objectives

L 1 - Observation and analysis of what happens in the Gauss cannon

L 2 - The energy considerations in a magnetic field.

Setup

Equipment from the kit: X2 + F + V15

X2 2 pcs. of cylinder magnets 12 diameter x 6 mm

F 4 pcs. of steel balls

V15 1 pc. U-shaped plastic profile

Join the two magnets and put them in the profile. Attach the 3 steel balls to the left side of the magnets.

Activity description

Release the fourth steel ball towards the right side of the magnets. Observe what happens when the ball hits the magnets.

How would you explain what is happening?

Minds-on questions

- The steel ball coming out to the left has considerably greater speed, and hence greater kinetic energy, than the ball to the right when you release it. Where does the energy come from?
- What happens to the speed of the ball if you use 3 or 4 magnets instead of the two?
- What happens if you use fewer or more balls to the left of the magnets?

3.4 Earth magnetic field

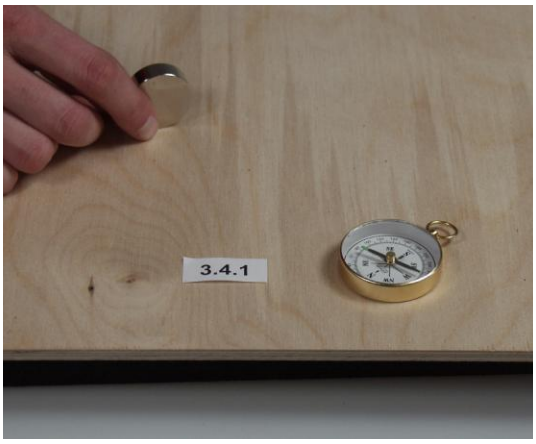
3.4.1 The unwilling magnet

Learning objectives

L 1 - Observe how a cylindrical magnet behaves when it rolls down an inclined plane.
L 2 - Become aware of the impact of Earth's magnetism.

Setup

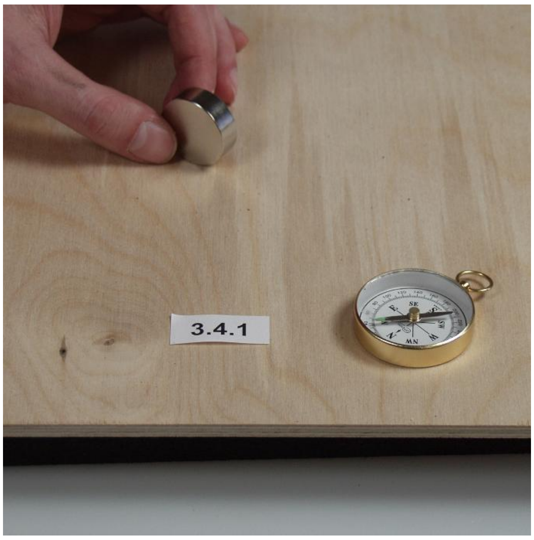
Equipment from the kit:
X5 + T1 + T2
Set the foam bevel T1 on a flat table without support elements of steel or iron. Place the wooded plate at an inclined plane.



The foam bevel and wooden board are placed on a cardboard box to get the necessary distance from the steel elements in the table.

Activity description

Roll the cylindrical magnet downward inclined plane. Notice how it moves. Turn the magnet and see how it is now moving. Try different angles. Use the compass to determine direction to the north and the south poles of the magnet. Use this information to explain what you observe.



Minds-on questions

- How does the magnet roll when the inclined plane is directed north-south?
- How does the magnet roll when the inclined plane is directed south-north?
- How does the magnet roll when the inclined plane is directed east-west?
- How does the magnet roll when the inclined plane is directed west-east?
- What happens when the magnet is turned?
- Is it possible to determine where is the direction to the north, just by placing the inclined plane in different directions and then rolling a magnet?

3.4.5 Rolling magnetic ball

Learning objectives

L 1 - Describing the movement of a magnetic ball rolling down an inclined aluminium track
L 2 - Explaining the observations using Lenz's law

Setup

Equipment from the kit:
T1 + T2 + V15 + X6
Let a magnetic ball roll down the inclined aluminium track. Describe its motion.

Explain the motion by means of Lenz's law.
Why does it move sometimes jerkily, sometimes not?
Mark the magnetic poles. How does the motion depend on the position of the poles?

Minds-on questions

- Is it possible to determine what is the direction to the north just by placing the inclined plane in different directions and then rolling a magnet?
- What will happen if you increase the angle of inclination regularly?
- What will happen if you put the ball on a flat plain far away of magnets and iron?
- What happens when the magnet is turned?

3.5 Magnetic effect of current

3.5.1 Magnetic field from a wire (Ørsted experiment)

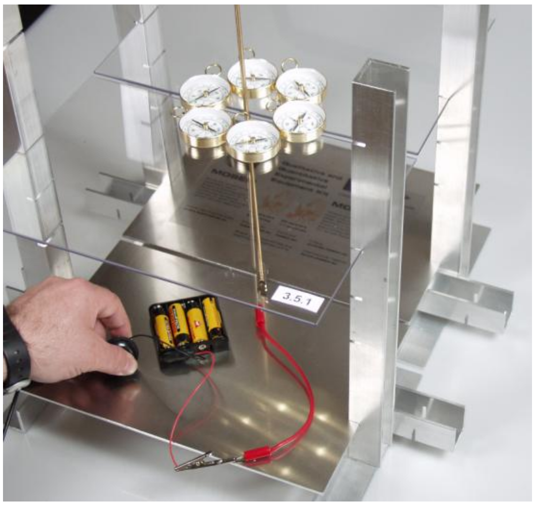
Learning objectives

L 1 - Investigate the experiment: observe the direction of compasses
L 2 - Analyse a given situation with regards to (invisible) magnetic field and the electric current. Investigate how to predict the orientation of the compasses: which factors are important

Setup

Equipment from the kit:
T9/T10/U1/V1 + V13 + W2/W4/W9/W10/M/L/N3/W11 + B

1. Picture of experimental setup: a wire is held vertically and connected to a power supply. The orientation of the current can be altered
2. List of needed materials: look at the picture
3. Hints: test the compasses before using them. Some can be influenced (remagnetised) by strong magnets, or might have lost their magnetism.



Minds-on questions

- Predict the orientation in which the compass will direct, given its position and the orientation of the current.
- What would happen if one doubled the current in the wire?
- What would happen if one took opposite direction for the current??

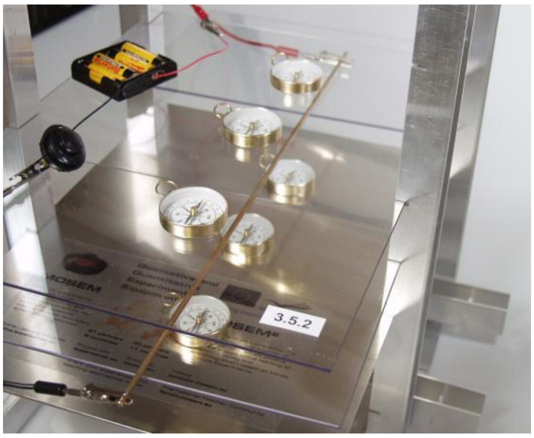
3.5.2 Ørsted experiment, horizontal version

Learning objectives

L 1 - Investigate the experiment: observe the direction of compasses

L 2 - Analyse a given situation with regards to (invisible) magnetic field and the electric current. Investigate how to predict the orientation of the compasses: which factors are important?

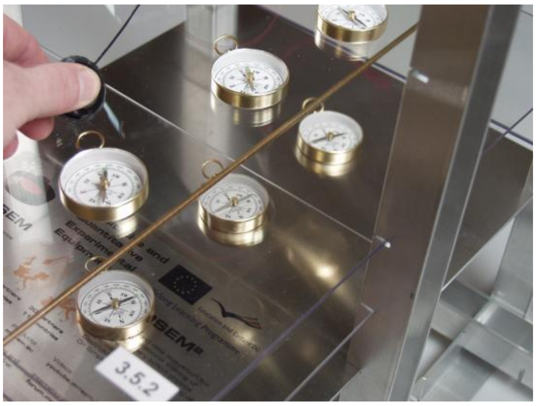
Setup



Equipment from the kit:
T7/T8/T9/U1/V1 + V13 +
W2/W4/W9/W10/M/L/N3/W11 + B

1. Picture of experimental setup: a wire is held horizontally and connected to a power supply. The orientation of the current can be altered.
2. List of needed materials: look at the picture

Hints: test the compasses before using them. Some can be influenced (remagnetised) by strong magnets, or might have lost their magnetism.

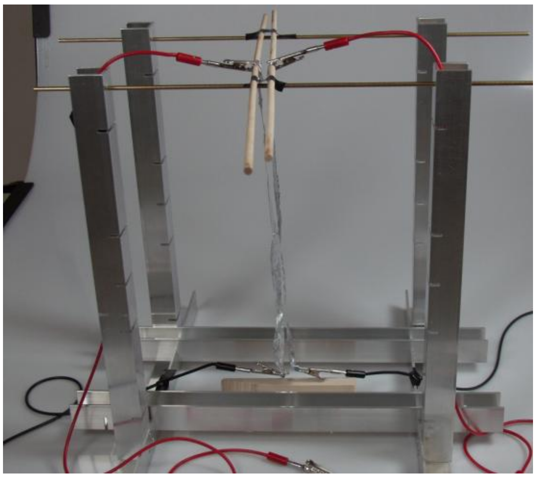


Minds-on questions

- Predict the orientation in which the compass directs, given its position and the orientation of the current.
- What would happen if one doubled the current in the wire?
- What would happen if one took opposite direction for the current?

3.5.3 Magnetic force between parallel wires (Ampere experiment)

Learning objectives



L 1 - Observing the forces acting on the aluminium wires

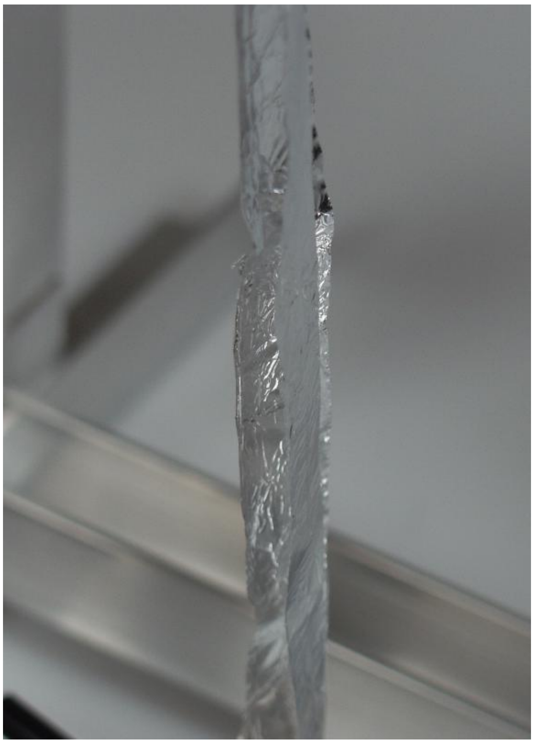
L 2 - Understanding the relationship between current directions in the wires, the magnetic fields and the forces acting

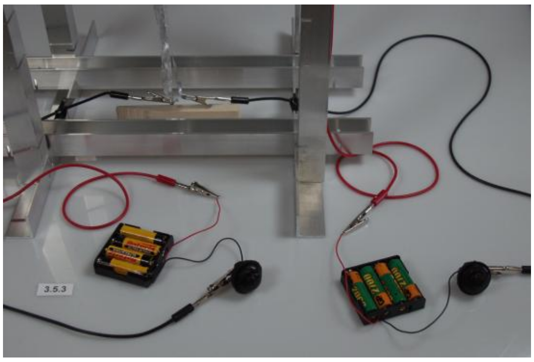
L 3 – Understanding a difference of the forces acting between two current-carrying wires and forces acting on a compass, as shown in experiments 3.5.1 and 3.5.2.

Setup

Equipment from the kit:
U1/V1/V13 + V12 + T3 (2 strips) +
W2/W4/W9/W10/M/L/N3/W11 + V32/H3
The experimental table to hold the brass rods.
A narrow aluminium strip, approx. 50 cm long and 1 cm wide, cut out of aluminium foil.

The Al strips are hanging from the wooden rods put on the brass rods. At the bottom, the ring magnets X4 are placed on each side of the wooden magnet separator (V19) to hold two alligator clips, to prevent the strips from touching each other. Tighten the aluminium strips so that they hang parallel, side by side, some millimeters from each other as shown on the right.





In this setup, the current in the two aluminium strips will always flow in opposite directions, so it is only possible to demonstrate repulsion between the conductors. A multimeter is connected into the circuit so that the current through the wire/foil can be read.

Heat can be generated quickly: be careful!

Activity description

Make sure that the two aluminium strips are a couple of millimeters apart. Predict, before turning the power on, if the foils will move towards each other or repel each other.

Connect the circuit using the button switch. The current is high so do not leave it running for a long time. Since the resistance of the circuit is very low, you are practically circuiting the battery/batteries.

Observe what happens with the strips. Read out the current with the multimeter.

Minds-on questions

- Predict, before the experiment is performed, whether the Al foils will move towards each other or repel each other.
- What will happen if the power is doubled?
- What will happen if the current flow in the same direction in the two strips?

Evaluation of LTK materials and activity description

In this example we have chosen an easy solution in which the strip is continuous and is simply hung over the brass rod. Such a setup will never be able to demonstrate what happens when the currents flow in the same direction.
The measured current in the aluminium strip is approx. 5 A with four AA batteries connected in series (4.8 V).

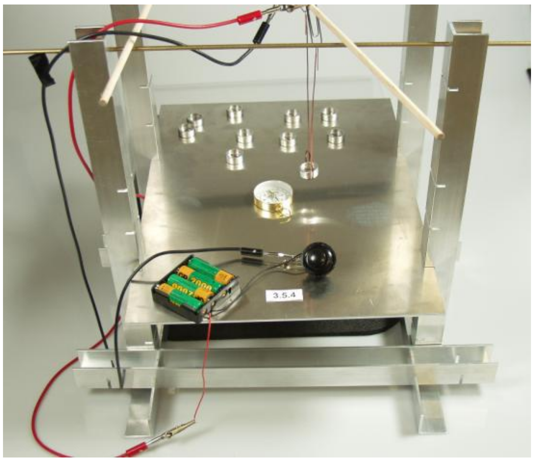
3.5.4 Field inside/around loop or solenoid

Learning objectives

L 1 - Investigate the magnetic field inside/around solenoid as a function of current and as a function of distance along the solenoid.

Setup

Equipment from the kit:
X10,X11,X12,V29,V30,V31 +
W2/W4/W9/W10/M/L/W11/N3 + V32/H3 + G.

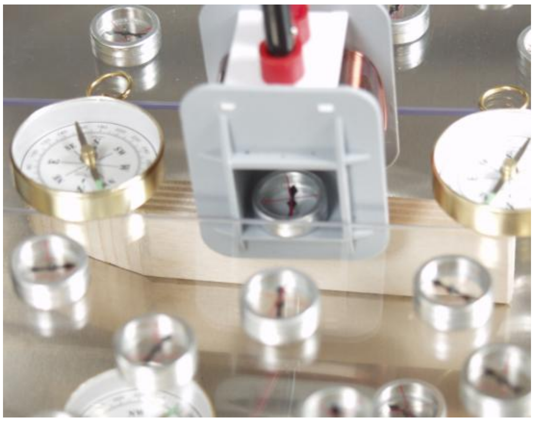


Activity description

Investigate the magnetic field inside/around solenoid with compasses.

Minds-on questions

- What is the direction of the magnetic field inside the solenoid? Explain the direction applying the right hand rule.
- What is the direction of magnetic field outside the solenoid?
- What is the peculiarity of field lines that suggests that the magnetic field within a solenoid can be considered homogeneous?
- What happens with the magnetic field inside loop/around solenoid with the increase of current in the wire?
- What happens with the magnetic field along the solenoid through which direct current flows?
- What happens with the magnetic field inside the solenoid with a ferromagnetic core?

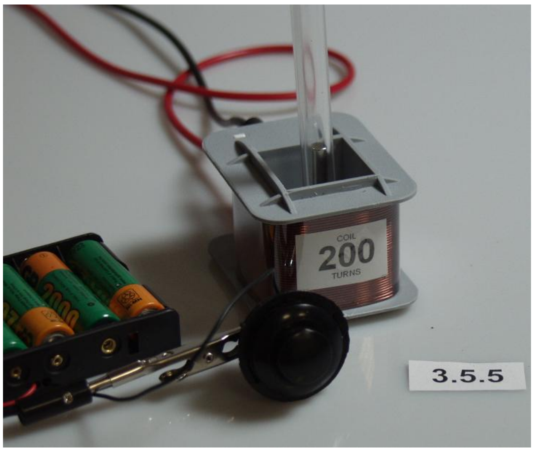


3.5.5 Repelling force: solenoid and magnet with gravity

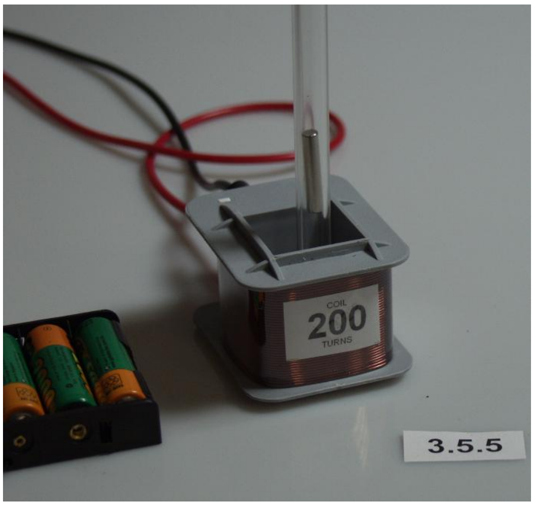
Learning objectives

L 1 - Observe how a current-carrying coil attracts or repels a magnet that is lowered into the coil.

Setup



Equipment from the kit:
V29,V30,V31 + V2 + W2/W4/W9/W10/M/L/W11/N3 + V32/H3 + V7 + V12 + X1 + T6
L 1 pc. switch
M 6 pcs. alligator clips
N3 1 pc. battery holder
T6 1 pc. ruler 50 cm
V2 1 pc. plexiglass ring 40 mm
V7 1 pc. pleksiglass tube 10 mm
V29 1 pc. coil 200 windings
V32 1 pc. multimeter
W2 2 pc. black lab. wires
W4 2 pcs. red lab. wires
W11 4 pcs. 1.2 V AA batteries
X1 1 pc. magnet stick Ø = 5mm, 25mm long
Wooden plug to close the end of the plexiglass tube.
The plexiglass tube sealed at the bottom using a plug made from a piece of one of the wooden sticks. Use paper or other soft material around the wooden stick to fit the pipe. The plexiglass ring is placed under the coil so that it sticks out slightly from the base. This allows the magnet to be completely inserted into the coil without hitting the table.



Activity description

Slip a magnet into the plexiglass tube sealed at the bottom with a wooden plug. Hold the plexiglass tube down in the coil, switch the power on and see that the magnet jumps up in the pipe. Measure how high the magnet jumps up. Learn how deep in the coil magnet must be lowered to jump up as high as possible.

Examine how high magnet will hover above the edge of the coil when it is powered.

Minds-on questions

- How does the magnet's levitation height above the coil depend on the current intensity?
- What happens to the magnet if we change the current direction in the coil?

Evaluation of LTK materials and activity description

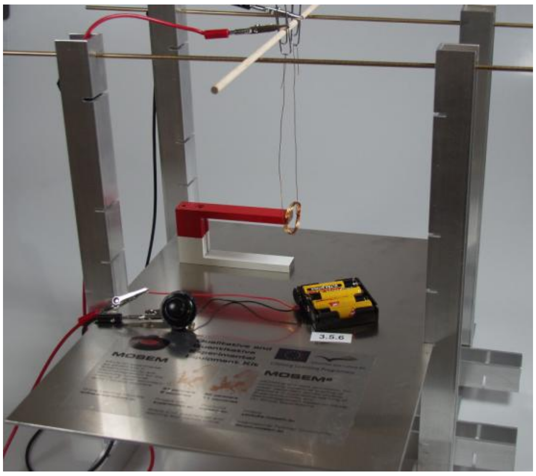
A small plug that fits the thin plexiglass tube is in the box. Alternative stopper can be made as described above.

3.5.6 Interactions between different coils and magnet

Learning objectives

L 1 - Observe that a current-carrying coil will interact with a magnet. Recognize that a current-carrying coil generates a magnetic field like a magnet.
L 2 - Observe that the force acting between the coil and the magnet depends on the current direction and the orientation of the magnetic field.
L 3 - Observe that the force depends on the current intensity, field strength and number of windings.

Setup



Equipment from the kit:
T8/U1/V1/V13 + V12/E4 + X10,X11,X12 + W2/W4/W9/W10/M/L/W11/N3 + V32/H3 + V23 + V19
L 1 pc. pressure switch
M 6 x alligator clips
N3 1 pc. battery holder
T9 1 piece plexiglass plate 200 x 300 x 3 mm
U1 2 pieces aluminium legs to experimental table
V1 2 pieces cross bar of aluminium to experimental table
V13 1 pc. brass rod 4 mm
V19 1 pc. wooden magnet separator
V23 1 pc. U-magnet
W2 2 pcs. black lab. cord 100 cm
W4 1 pc. red lab. cord 100 cm
W11 4 pcs. AA batteries 1.2 V
X10 1 pc. copper loop with 1 turn
X11 1 pc. copper loop with 10 turns
X12 1 pc. copper loop with 20 turns
1 pc. straw for isolation

The coil is mounted on the paper clips, which are firmly pinched by crocodile clamps to the wooden rod. The height of the U-magnet is adjusted so that its one end/leg passes through the coil. Fine tuning can be done by tilting the crocodile clamps up or down. Check that the coil can slide freely to the u-magnet. In this experiment it is enough to start with one battery only, since the reaction is quite strong.

Activity description

Use one battery
• Select the coil with 10 turns (X11) and record the effect when the power is switched on.
• Turn the magnet, what happens to the angle of inclination?
• Change the current direction, what happens to the angle of inclination?
• Select the coil with 1 turn (X10) and record the effect when the power is switched on.
• Select the coil with 20 turn (X12) and record the effect when the power is switched on.

Use two batteries (increase current and voltage)
• Select the coil with 10 turns (X11) and register the angle of inclination when the current is switched on.
We notice that a current-carrying coil behaves like a magnet. We have an electromagnet. An electromagnet has a number of advantages over a permanent magnet:

1. Polarity can be turned by turning the current direction.
2. The force can be changed by changing the current, ev. number of windings.
3. Magnet can be switched on and off.

The magnetic field of an electromagnet can be made stronger by inserting a ferromagnetic material into the coil.

Minds-on questions

- What happens to the forces acting on the coil when the current is switched off?
- Attempt to predict in which way the force exerted on the coil depends on the power direction and direction of the magnetic field.
- What happens to the inclination angle if we turn the magnet?
- What happens to the inclination angle when coils with different number of turns are used?
- What happens to the inclination angle if we increase the diameter of the coil, but keep the same number of turns?
- Compare interaction between a coil and a magnet, with interaction between two magnets. What differences and similarities are there between these two situations?
- How will you explain what you see from your knowledge of magnetic fields around a coil or solenoid and a magnet?

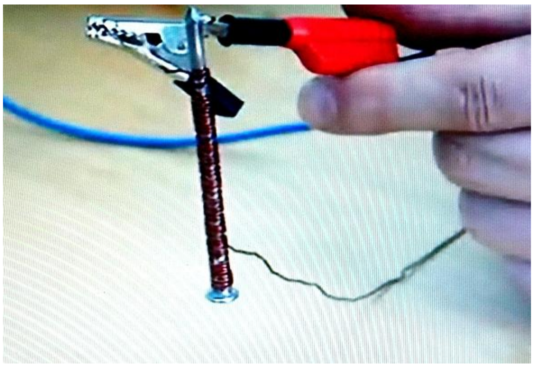
Evaluation of LTK materials and activity description

The reaction in this experiment is very strong and should perhaps be restricted in order to clarify the phenomenon to be observed. This can be done by reducing the number of turns and power, but also by pulling the magnet out of the coil so that it is placed edge to edge with the coil.

3.5.7 Iron core vertically attracted inside a coil

Learning objectives

L 1 - Investigate the magnetic field created from a coil with iron core as a function of the current.



Setup

Equipment from the kit:
V29,V30,V31 + V17, J1 +
W2/W4/W9/W10/M/L/W11/N3 + V32/H3

Activity description

See the picture.

Minds on questions

- What is the direction of the magnetic field inside the coil? Explain the direction applying the right hand rule.
- What is the direction of magnetic field outside of coil?
- What is the peculiarity of field lines that suggests that the magnetic field within a coil can be considered homogeneous?
- What happens with the magnetic field inside the loop/around coil with the increase of current in the wire?
- What happens with the magnetic field along the coil, with iron core, through which direct current flows?
- What happens with the magnetic field in coil with ferromagnetic core when the current is switched off?

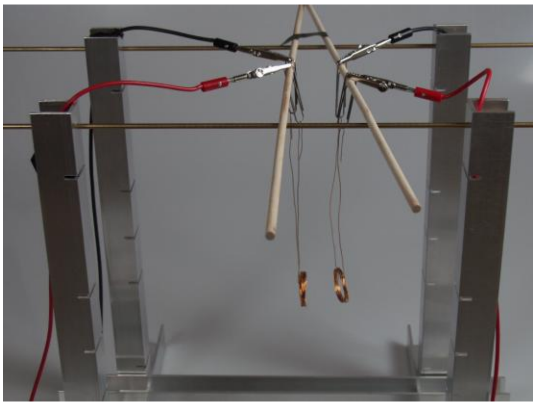
3.5.8 Attraction/repulsion of two coils

Learning objectives

L 1 - Observe the forces that occur between the two coils when the power is being supplied to them.

L 2 - Observe that the forces' direction depends on the current direction. Repulsion occurs when the currents flow in the opposite direction and attraction occurs when they flow in the same direction.

L 3 - Observe that the force depends on the current intensity.



Setup

Equipment from the kit:

U1/V1/V13 + V12/E4 + X11 + W2/W4/W9/W10/M/L/W11/N3 + V32/H3

L 1 pc. pressure switch
M 10 Pack alligator clips
N3 1 pc. Battery Holder
T9 1 piece plexiglass plate 200 x 300 x 3 mm
U1 2 pieces aluminium legs to experimental table
V1 2 pieces aluminium cross bar to experimental table
V13 1 pc. brass rod 4 mm
W2 3 pcs. black lab. cord 100 cm
W4 2 pcs. red lab. cord 100 cm
W11 4 pcs. AA batteries 1.2 V
X11 2 pcs. coils with 10 turns
1 pc. straw for isolation

The coils are mounted on four paper clips, which are firmly pinched by crocodile clamps to the wooden rods. Coils are mounted in a distance of 5 to 10 mm between them. See the details in the picture - the figure shows the electrical connection. The currents in the two coils have opposite directions and thus the coils will repel each other.

Activity description

1. Connect the circuit so that the currents run the same direction through both coils.
2. Use the right hand rule to identify the north and south poles of the coils.
3. Predict whether the coils will attract or repel each other.
4. Observe what happens to the coils when the power is turned on.
5. Connect the circuit so that the currents flow in the opposite directions through both coils.
6. Use the right hand rule to identify the north and south poles of the coils.
7. Predict whether the coils will attract or repel each other.
8. Observe what happens to the coils when the power is turned on.

9. If the coils are powered separately, the current intensities in the coils may be different. Examine what happens if the current in the one coil is changed from being equal to half of the current in the other.
10. Find a connection between the current direction in the coils and the direction of the forces between the coils.

Minds-on questions

- What happens to the forces acting on the coil when the current is switched off?
- Attempt to predict in which way the forces exerted on the coils depend on the power direction and direction of the magnetic field.
- What happens to the angle of inclination when coils with different number of turns are used?
- What happens to the angle of inclination if we increase the diameter of the coil, but keep the same number of turns?
- Compare interaction between two coils with interaction between two magnets. What differences and similarities are there between these two situations?
- How will you explain what you see from your knowledge of magnetic field around a coil?

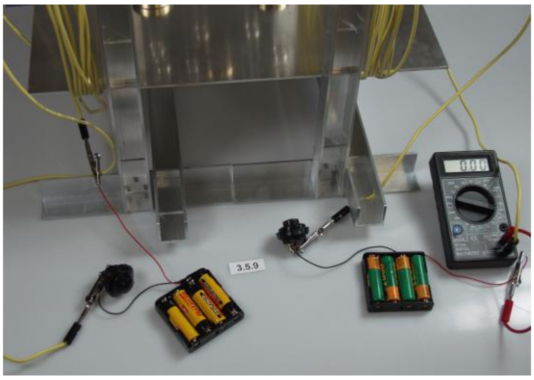
Evaluation of LTK materials and activity description

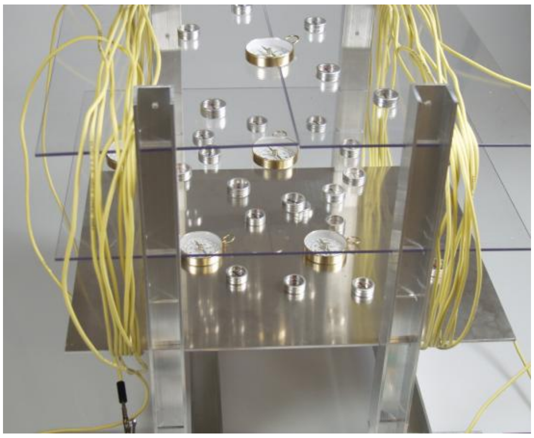
The straw works very well as an insulation between the crocodile clamps and the brass rod. The advantage of using the brass rod instead of insulating rod is that it fits the holes drilled in the legs of the table. Moreover, it also fits well the gap of the crocodile clips.

3.5.9 Field in Helmholtz coils

Learning objectives

L 1 - To analyse the magnetic field generated by a pair of Helmholtz coils.





Setup

Equipment from the kit:
T7/T8/T9/U1/V1 + W1/W9/M/L/N3/W11 + V32 + B, G.

Activity description

A Helmholtz pair consists of two identical circular magnetic coils that are placed symmetrically one on each side of the experimental area along a common axis, and separated by a distance equal to the radius R of the coil. Each coil carries an equal electrical current flowing in the same direction. The use of compasses allows one to investigate a field between such coils.

Minds on questions

- Is the field uniform?
- How does the region of uniform magnetic field vary with parameters of the setting?

3.6 Lorentz Force

3.6.1 Magnetic force on a wire (Pohl experiment)

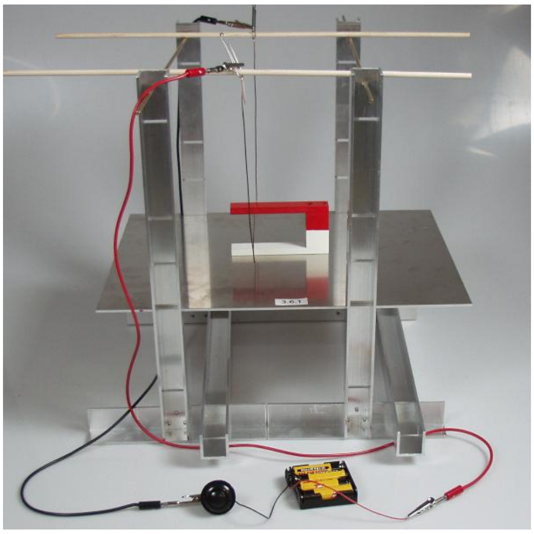
Learning objectives

Observe the direction of the Lorentz force

Investigate how the deflection angle of the wire depends on the current, strength of magnet and length of wire hanging in the magnetic field

Setup

Equipment from the kit:
T8/U1/V1/V13 + V12/E4 + X7 +
W2/W4/W9/W10/M/L/W11/N3 + V32/H3 + V23
(X2, X4, X5)



1. Pictures of experimental setup: two possibilities (one with strong magnet, the other one with U-shaped magnet (link to computer application).
2. List of needed materials: look at the picture + second strong magnet or U-shaped magnet.
3. Hints and Warnings: using a strong magnet needs a special attention; make sure to have a spare battery; apply current only during short time intervals.
4. Look at the online animations and make sure the setup corresponds to that image. (N/S and +/- orientation).

Minds-on questions

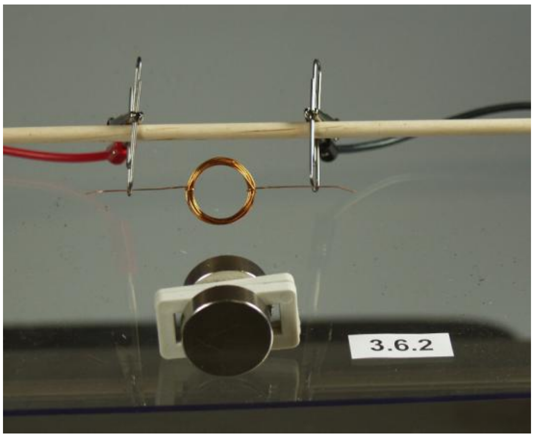
a. What would happen with the deflection angle of the wire if one would double the current in the wire?
b. What would happen with the force exerted on the wire if one turns the magnet along its own two horizontal axes?
c. What would happen with the force exerted on the wire if one puts two identical magnets instead of the one under the wire?
d. What would happen with the force exerted on the wire if one lifts the magnet above the wire (keeping it in the same position)?
e. What would happen with the force exerted on the wire if one takes two magnets, under and on the top of the wire, facing the like poles/ the opposite poles?
f. What would happen with the force exerted on the wire if one takes two magnets, under the wire, facing the opposite poles?

3.6.2 Turning coil between magnets

Learning objectives

L 1 - Observe and examine the direction of the Lorentz force.
L 2 – Analyse the field image around a coil in a given situation (a rotating coil), with respect to a current direction in the coil and the Lorentz force that occurs.
L 3 - Investigate and explain where and how the Lorentz force acts on a coil.
L 4 - Understand how the Lorentz force acting on the coil creates a torque in rotational direction so that the coil is turned around.

Setup



Equipment from the kit:
T8/U1/V1/V13 + V12/E4 + X8 + W2/W4/W9/W10/M/L/W11/N3 + V32/H3 + V23 (X2, X4, X5) + V19
E4 2 pcs. large steel paperclip
M 4 pcs. alligator clips
N3 1 pc. battery holder, 4 pcs. AA
U1 2 pcs. experimental table part 5, feet
V1 2 pcs. experimental table portion 6, the stabilization rods
V12 1 pcs. wooden rod
W2 1 m black wire with banana sticks
W4 1 m red wire with banana sticks
X5 2 pcs. neodymium magnet 30 mm
X8 1 pc. straight copper wire with loops

Set up the experimental table. Put the wooden rod through the bottom holes in the table legs (they are drilled in addition to the original ones) so that it is about 10 cm above the plexiglass top of the table. Mount two large steel paperclips to the rod.

Activity description

Hang the coil X8 on the two brackets formed by the paperclips and place the magnets under the coil. Connect the clips with the batteries using red and black wires with banana sticks and crocodiles. The coil will now rotate with high speed. Put a piece of styrofoam on the coil if it goes out to one side. If the coil does not rotate, check the following:

- Help the coil get started.
- Check that the batteries are charged.
- Check that there is a good connection between battery and paper clips.
- Check that the insulation is correctly removed along the shaft the coil.

Minds-on questions

Investigate what happens if you:

- reverse the voltage of the battery,
- reverse the poles of the magnet,
- keep the magnet on the side or on the top of the coil,
- double the current intensity through the coil?

What will happen if the coil wire is very thin and the magnet is very strong?

Evaluation of LTK materials and activity description

Insert a little bit of foam or polystyrene, preferably a thin disc, which can stop the coil from sticking too far out of one side.

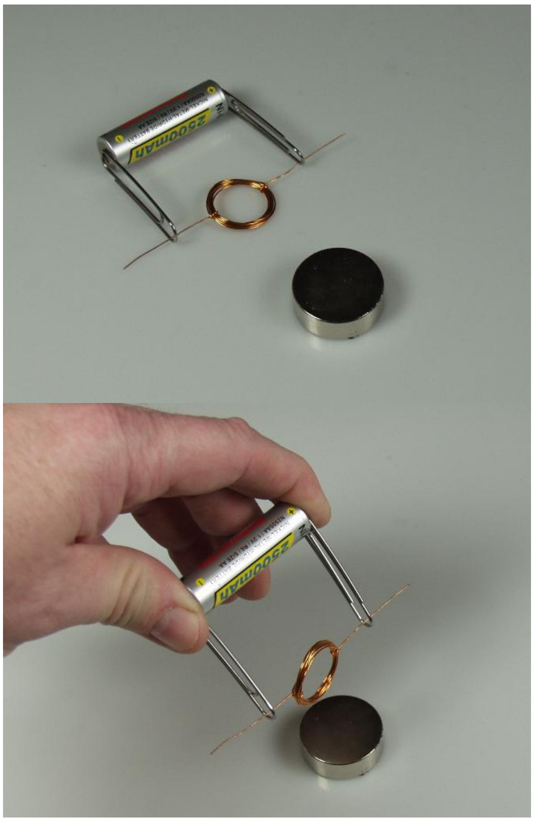
The engine works very well in both cases: when the magnet is held above or below the coil. The direction of the rotiation changes with the position of the magnet. When the magnet is held aside of the rotor, it cannot decide which direction to rotate.
The paperclips should be not magnetic, in order not to attracted by the magnet, disturbing the setup.

3.6.3 Rotating coil motor (paperclip motor)

Learning objective

Observe the direction of the Lorentz force.
Analyse a given situation with regards to (invisible) magnetic field, the electric current and the Lorentz force that is generated.
Investigate where and how the Lorentz force acts on circular wires of the mini coil.
Integrate the concept of angular momentum with the set of Lorentz forces acting on the coil.

Setup



Equipment from the kit:
W11 + E3 + X8 + X5

1. Picture of experimental setup: two paperclips hanging from the horizontal battery serve as support for the coil.
2. List of needed materials: look at the picture.

Hints: using strong magnets is spectacular; just take care they do not attract the paperclips instead of interacting with the coil… and Warnings: using a strong magnet needs special attention; make sure to have a spare battery; apply current only during short time intervals.

Activity description

Bend the paperclips so that they form a double hook. The smallest hook is bent in the top so that it forms a loop. The shafts of the coil are bent slightly to the side so they can remain in place while turning. Put it into the loops.

It can also be a need to increase the distance between the loops. The paperclips are pressed against the terminals of the battery with thumb and forefinger. Then lower the engine slowly down towards the magnet.

Using one of the biggest magnets remember to keep enough distance.

Minds-on questions

- Try to predict the rotation direction of the coil.
- What will happen if the coil is hung exactly above the center of the magnet?
- What happens if the coil is moved slightly forward or slightly back from the center?
- What will happen if one increases the current intensity twice?
- What will happen if the magnet is turned around?
- What will happen if one turns the power orientation (i.e. turns the battery)?
- What will happen if the magnet is moved on the top of the coil (between coil and battery)?

Evaluation of LTK materials and activity description

It was found necessary to make small loops of the paperclips where the coil should be hung, in addition the ends of the shaft were bent slightly to the side. In addition, the paperclip hooks were bent slightly apart in order to reach the exposed parties of the cord along the coil shaft.

3.6.4 Homopolar motor, rotating wire (one loop motor)

Learning objectives

L 1 - Observe the direction of the Lorentz force.

L 2 - Analyse a given situation with regards to (invisible) magnetic field, the electric current and the Lorentz force that is generated.

L 3 - Investigate where and how the Lorentz force acts on the wires of the loop at different places.

L 4 - Integrate the concept of angular momentum with the set of Lorentz forces acting on the coil.

L 5 - Realize that the magnet serves as a conductor here.

Setup

Equipment from the kit:
W11 + X5 + J10 (J1 + V28)

1. Picture of experimental setup: one strong magnet attached to the bottom of the battery. The loop is placed on the top of the battery. Make sure the loop touches the magnet gently (at least sometimes).
2. List of needed materials: look at the picture.

Hints: using strong magnets is very spectacular. Warnings: using a strong magnet needs special attention; make sure to have a spare battery; apply current only during short time intervals.

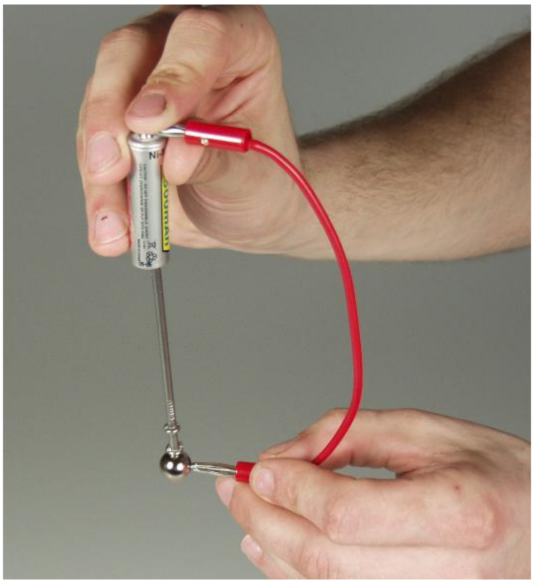
Minds-on questions

- Predict the orientation in which the loop will turn.
- What would happen if one doubled the current in the loop?
- What would happen if one turned the magnet poles?
- What would happen if one changed the current direction in the loop?
- If the loop was not closed (at the top of the battery), would it turn?
- If the loop had only one ‘arm’, would it turn then?

3.6.5 Homopolar motor, rotating magnet

Learning objectives

L 1 - Observe the Lorentz force.
L 2 - Examine the layout with respect to the magnetic fields and electric currents that work together to create the rotation.
L 3 - Examine the Lorentz force.
L 4 - Realize that the magnet acts also as a conductor.
L 5 - Realize that the Lorentz force actually acts on the charge carriers and not on the cord or magnet as such.



Setup

Equipment from the kit:
W11 + J1 + X2, X5 + W3

1. Picture of experimental setup: one strong magnet attached to the bottom of the battery, with a nail in between (to enhance proper, almost frictionless rotation).
2. A conducting flexible wire touches the top of the battery and the magnet at the bottom.
3. List of needed materials: look at the picture.

Hints: using strong magnets is very spectacular.
Warnings: using a strong magnet needs special attention; make sure to have a spare battery; apply current only during short time intervals, the top of the battery can get hot.

Activity description

Attach the magnet to the nail head and make sure it is centered. Contact the nail with the one battery pole, either the plus or the minus one – the plus pole turned out to be more convenient. Connect the second pole of the battery and the magnet using the cord. It may be useful to create a notch in the battery so that the tip of the nail stays in place.

Minds-on questions

- Try to predict the rotation direction of the magnet before connecting by the cord.
- What happens to the rotation if the battery poles are reversed?
- What happens to the rotation if the magnet poles are reversed?
- What happens if the current is doubled?

3.6.6 Reverse generator – simple electrical motor

Learning objectives

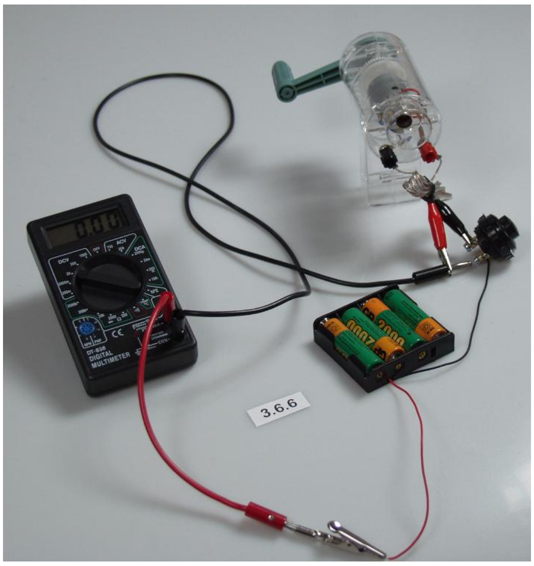
L 1 - Improve understanding of the Faraday-Newmann-Lenz law.
L 2 - Improve understanding of the conversion of electrical into mechanical energy.
L 3 - Investigate how the angular velocity depends on applied voltage.

Setup

Equipment from the kit: V20/H4 + V32 + W2/W4/W9/W10/M/L/W11/N3

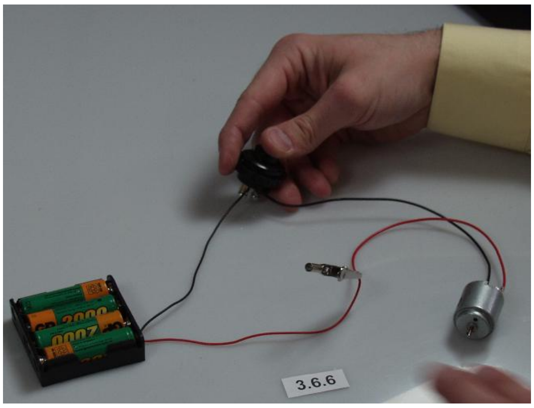
Activity description

List of needed materials: Hand Generator, batteries in series, chronometer.
How to use this set up: Connect the hand motor to a series of batteries. Change the number of connected batteries and each time evaluate the angular velocity.



Pedagogical aims

Before doing anything, ask the question "What do you expect to happen if you connect the hand motor to a series of batteries?"
Let the students first realize the experiment and let them report about their observations. Then ask to point out "what do you think is happening?"
The physics of the experiment: this experiment is an example of the conversion of electrical into mechanical energy using the Faraday-Newmann-Lenz law. It allows to evaluate the angular velocity of the hand motor, when it is connected to batteries.



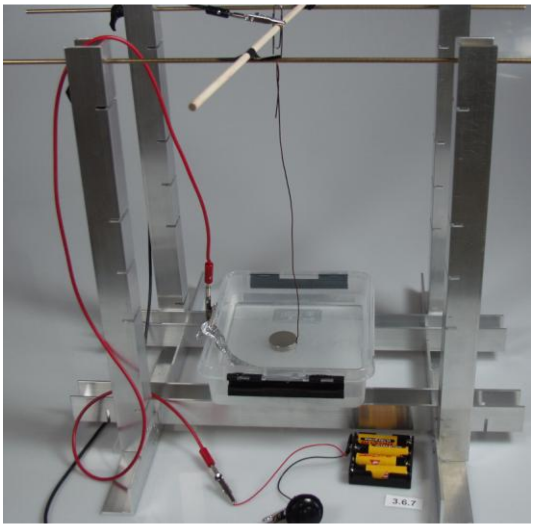
Minds-on questions

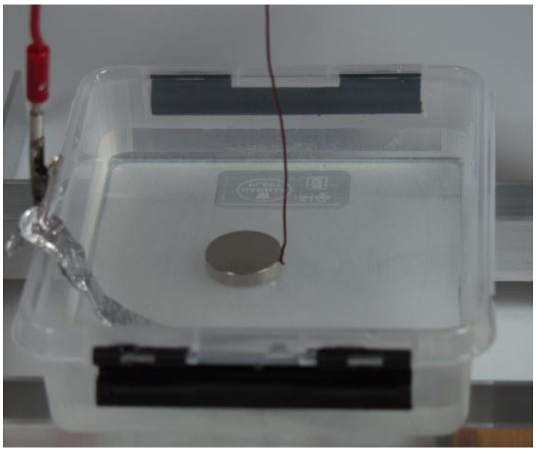
- Do you need some energy to allow a crank turning?
- Can the crank turning be related to the batteries connected in series?
- Can you describe in detail and in the correct sequence the physics processes involved, in particular those linked to energy transformation?

3.6.7 Faraday motor

Learning objectives

L 1 - Observe and explore the Lorentz forces on current-carrying wire in magnetic field.
L 2 - Analyse and interpret observations.





Setup

Equipment from the kit:
T8/U1/V1/V13/E3 + V4 +
W2/W4/W9/W10/M/L/W11/N3 + T3 + X4, X5 +
salt + water in V24 box
L 1 pc. pressure switch
M 6 x alligator clips
N3 1 pc. battery holder
T3 1 strip width approx. 3 cm x 40 cm
U1 2 pieces aluminium legs to the experimental table
V1 2 pieces aluminium cross bar to the experimental table
V13 1 pc. brass rod 4 mm
W2 2 pcs. black lab. Cord 100 cm
W4 1 pc. red lab. Cord 100 cm
W11 4 pcs. AA batteries 1.2 V
X4 1 pc. magnet
50 cm uninsulated ring cord,
1 pc. plastic box (usually used to hold magnets)
1 tablespoon salt
2 dl water

Make a small hook from an uninsulated wire and hang it in the middle of the wooden rod. Use a crocodile clip to connect the hook to the minus pole of the battery (see the picture). Make a pendulum from the rest of the uninsulated wire. The pendulum should be long enough to reach the salt bath in the plastic box half filled with saline solution (1 tablespoon salt in 2 dl. of water). The box is located at the bottom of the experimental table. Place a strip of aluminium foil (about 3 cm wide) at the bottom of the plastic box. The aluminium foil protrudes from the edge of the plastic box so the plus pole of the battery can be attached to the foil. Place a magnet on the aluminium foil in the middle of the plastic box.
Make sure the pendulum can swing freely and does not touch the bottom or aluminium foil in the bottom.

Activity description

Switch the current on and observe what happens to the pendulum. If the pendulum does not start moving, it's probably a bad electrical contact in the suspension. Try to drip a little saline solution onto the suspension. Describe the movement of the pendulum.

Minds-on questions

- What is the role of the saline solution?
- Try to predict the rotation direction of the pendulum before turning the power on.
- What happens to the movement of the pendulum if the battery poles are reversed?
- What happens to the movement of the pendulum if the magnet poles are reversed?
- What happens if the current is increased or decreased?

High-Tech Kit Workbook

Overview and contents

This section shows all elements of the High-Tech Kit (HTK) inside foam nests together with their short descriptions - brackets indicate activity numbers where the elements are used.

Bottom compartment

1. Dewar – a container for liquid nitrogen {4.1}, inside the dewar an external power supply 5V, 2,5A is stored
2. Superconducting probe for USB measurements {4.1.1}
3. Metal probe for USB measurements {4.1.2}
4. Semiconducting probe for USB measurements {4.1.3}
5. Field apparatus for Hall measurements {4.5}, the foam cover is also used as a stand for the Hall probe when it is inserting between magnets of a field apparatus
6. Box for small parts of the kit (detailed description below)
7. A foam bowl in a plastic holder {4.3}
8. Five plastic beakers {4.3}
9. Two foam bowls {4.2, 4.3}
10. Magnetic train track {4.4}

Top compartment

11. Multimeter – temperature tester {4.6}
12. Multimeter – self inductance meter {4.6}
13. Magnetic field meter {4.2, 4.3. 4.4, 4.5, 4.6}
14. USB interface {4.1, 4.5}
15. USB cable {4.1, 4.5}
16. Two pairs of gloves
17. Two pairs of glasses
18. Coil {4.6}
19. Superconducting train {4.4}
20. Single magnet stand {4.4}
21. Alternating magnets stand {4.4}
22. Two 1.5 mm spacers {4.3, 4.4}
23. Two 4 mm spacers {4.3, 4.4}
24. Two 8 mm spacers {4.3, 4.4}
25. Container with 4 magnet discs 20 x 5 mm {4.2, 4.3}
26. Container with 20 magnet discs 9.5 x 1 mm {4.3}
27. Container with 10 rectangular magnets 20 x 5 x 3 mm {4.3}
28. Container with 10 magnet cubes 5 x 5 x 5 mm {4.3}

Foam tray insert

29. Aluminum foil – under the booklet {4.1.5}
30. Booklet with descriptions of the experiments – HTK Workbook
31. USB interface and SuperC program installation CD
32. Information for trolley user and keys

Box for small parts (item 6)

6.1 Set of cables for multimeter no 12 {4.6}
6.2 Three plastic tweezers (2 – 115 mm and 1 – 145 mm) {4.2, 4.3, 4.4}
6.3 Knife {4.4.5}
6.4 Piece of gadolinium {4.6}
6.5 Piece of graphite {4.4.5}
6.6 Two superconducting pellets with high pinning {4.3}
6.7 Four superconducting pellets with low pinning (2 rings {4.2}, 2 discs {4.3})
6.8 Box of matches {4.1.4}
6.9 Temperature sensor for multimeter no 11 {4.6}
6.10 Two metal rods {4.2}
6.11 Semiconducting Hall probe {4.5}
6.12 Paper clips {4.3.4}
6.13 External power supply adaptor with small 20 pins cable

List of HTK experiments

The content of the High-Tech Kit allows you to perform various experiments. The experiment numbers in the below list refer to a universal numbering system for all experiments and activities in both MOSEM and MOSEM^2 projects.

Numbers that are not included below refer to activities that are not described. Many of them belong to the Teacher Guide for MOSEM^2, and others will be included in future versions of the MOSEM Teacher Guide.

Experiments in black are provided with full descriptions while experiments in blue are associated with only short descriptions.

4. Superconductivity

4.1: Resistivity versus temperature

4.1.1 Resistance of a copper sample as a function of temperature
4.1.2 Resistance of a superconducting sample as a function of temperature
4.1.4 What is the temperature of liquid nitrogen?
4.1.5 The leaking beaker

4.2: Persistence of current

4.2.1 Demonstration of persistence of current in a superconducting ring

4.3: Discovering levitation

4.3.1 The Meissner Effect
4.3.2 Levitation: Meissner levitation and pinning compared
4.3.3 Levitation: testing the pinning
4.3.4 The 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 Superconducting train: first example
4.4.2 Superconducting train: bad example
4.4.3 Superconducting train: good example
4.4.4 Make your own train
4.4.5 Pyrolytic graphite on tracks

4.5: Hall effect

4.5.1 Measurement of the Hall coefficient for semiconducting samples

4.6: Gadolinium experiment

4.6.1 Investigating gadolinium with a multimeter
4.6.2 Investigating a superconductor with a multimeter

Full descriptions of HTK experiments

This section presents elaborated descriptions of HTK experiments – they are provided with worksheet and explanation sheet. Short descriptions of non-elaborated experiments are also presented.

Student Worksheet

In this kind of documents safety issues together with aims, apparatus and procedures necessary for the described experiment are presented. They are followed by minds on questions indicated with the symbol shown here.

Explanation sheet

Explanation sheets contain basic physics information related to each experiment.

Short descriptions of HTK experiments

This section presents short descriptions of non-elaborated HTK experiments which are not associated with student worksheet and explanation sheet. Instead of that they contain the following components.

Pedagogy and setup

Some remarks on how to approach the activity from the pedagogic point of view together with details/pictures for setting up each described experiment. This information should help teachers and students in using the activity.

Observations

This section gives detailed information what to observe.

Minds-on questions

The list of Minds-on questions empathizes intended use of the HTK non-elaborated experiments. This list might be extended by the teacher when performing an activity.

The physics of the experiment

Main physics information and principles that help understanding the observed behaviour are presented in the section.

4.1. Resistivity versus Temperature

4.1.1 Resistance of a copper sample as a function of temperature

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor. Brief contact of liquid nitrogen with skin is not dangerous, because it boils forming an insulating gas layer. However liquid nitrogen can become dangerous if it comes into contact with any garment: no rings or watches must be worn while manipulating.

Aim: to quantitatively investigate the dependence of the resistance of a metallic sample on temperature. For comparison also see video at:
http://www.youtube.com/user/MOSEMwp7#p/u/45/zEGOGQHqXIo

Apparatus: from the kit you will need

- the copper sample – no.3 and Al container with a wire to allow dipping it in LN;
- to put the sample inside container no.2 remove the o-ring;
- the USB interface with a USB cable – no.14 and 15.

Moreover you will need:

- a thermally insulated container (dewar or styrofoam cup) – no.1
- liquid nitrogen;
- a PC with the USB acquisition system (CD provided with the kit) installed;
- an external power supply (inside no.1) and power adapter – no. 6.13.

Fig. 4.1.1A Experimental set-up components.

Procedure:
Acquire the temperature and the resistance of the copper sample, while it is heating from about the temperature of the boiling liquid nitrogen to room temperature. Determine the relationship between resistance and temperature.

1. What graph will come out? Draw a draft. Mind the axis!

Connect the sample to the power adaptor and join it to the USB interface. Attach the power supply to power adaptor and plug it in. Connect the interface to the computer. Put the sample into Al container with mount wire as a handle.

Initiate the acquisition program and setup the correct gain for the acquisition by selecting the “Metals” option in the drop-down menu situated on the upper part of the screen. Press START button in the left part of the command bottom bar. In the pop-up menu that appears, make sure that the option “Enable Temperature Driving” is deselected, and press OK.

On the right part of the window, a table will be filled with the values of temperature (in kelvins) and resistance (in mohms) of the sample. At room temperature (about 300K) the resistance should be stable and amounts a few mΩ. Left to the table there is a graphical display of the relation between resistance (vertical axis) and temperature (horizontal axis): it must show a blur spot, confirming the steady state of the sample.

Pour the liquid nitrogen into the dewar or the styrofoam cup (the help of the teacher or of a technician is required) and dip the container with the sample in using handle. Observe the evolution of the temperature and resistance values, until a new steady state is reached, at a temperature below 100K.
When the steady state is reached, press the “Stop” button in the command bar.

When you are ready to start the actual measurement, press the START button. In the pop-up menu select the option “Enable Temperature Driving”, that enables the heating system of the sample. Choose the values for the final temperature in the measurement (up to the room temperature, 300K) and “Continuous mode”. When ready, press OK.
Observe the evolution of the temperature and resistance values, until the sample reaches the final temperature and the acquisition automatically stops.
Save on file the data acquired (button “Save”) and export them into a text format on another file (button “Export”). What graph will come out? Draw a draft.

2. What did you observe?

Estimate the R_0 value as well as the slope of the curve of the (T,R)-graph. Start a worksheet program (i.e. Excel) and open the text file with the exported data. Build a scatter plot graph of the resistance against temperature. Add a linear trend line to the data, showing the formula expressing the relationship between resistance and temperature.

Calculate from the formula the value R_0 of resistance at T=298K (25°C). Divide the value of the slope in the trend line by R_0 and report this value as your estimation of the thermal coefficient α for the resistivity of copper.

3. Can you explain your observations?

Explanation Sheet

1. The USB interface allows to acquire the values of temperature (from a PT100 temperature sensor) and resistance (measuring the difference of potential on the sample at a given current injected) of the copper sample.
The acquisition system can be used for resistance measurement of different materials, with different ranges of values for the electrical quantities. Because of this fact, the amplification of the ADC must be adjusted to fit the accuracy needed for the measurement, by selecting the appropriate measurement channel. In the phase 1 of the experience students must familiarize with the program interface, in particular with the tabular and graphical representation of the data acquired.

2. The boiling temperature for liquid nitrogen at atmospheric pressure is 77K, but due to thermal contact of the sample's vessel with the external environment, the steady state of the sample when the vessel is dipped in the nitrogen is above of that temperature (typically above 100K). In this phase students can observe the decrease of the resistance of the sample, as the temperature decreases, till reaching a steady state at a temperature near the boiling point of nitrogen.
In this phase, data for the correlation between resistance and temperature are taken out of thermal equilibrium and are affected by the thermal inertia of the experimental setup. Due to this reasons, it is suggested to discard such data in the analysis.

3. The heating system (enabled by the option "Enable Temperature Driving") consists of a resistor inserted in the support of the sample. The heater is powered cyclically, till the temperature increases to a desired value (start value plus the step) and then powered off. When the temperature temporarily stabilizes and the sample is almost at thermal equilibrium, the resistance is measured; then the procedure is repeated up to the maximum temperature chosen.
The typical duration of the experiment is about 1 hour.

4. The scatter plot graph R vs T shows an evident linear correlation between the two quantities.

The suggested calculations allow to evaluate the thermal coefficient α a T=25°C (α is defined as the linear coefficient in the approximate relation that express the temperature dependence of resistance $R(T) = R(T_0=25°C)\,(1 + \alpha\,(T-T_0))$).

Figure 4.1.1B shows the temperature dependence of the copper resistivity (data from CRC Handbook of Chemistry and Physics). The value of α obtained from these data is about $0.039K^{-1}$.

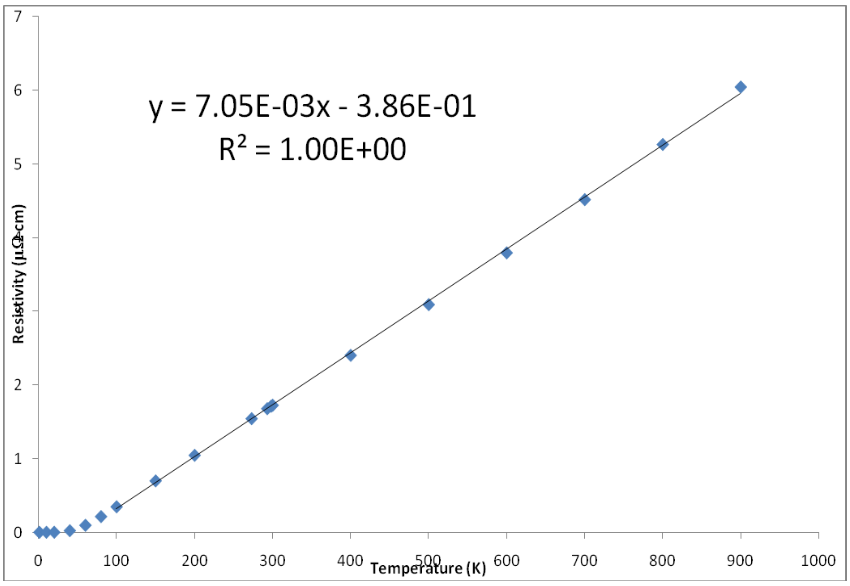


Fig. 4.1.1B Dependence of copper resistivity on temperature.

4.1.2 Resistance of a superconducting sample as a function of temperature

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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. Brief contact of liquid nitrogen with skin is not dangerous, because it boils forming an insulating gas layer. However liquid nitrogen can become dangerous if it comes into contact with any garment: no rings or watches must be worn while manipulating.

Aim: to determine the critical temperature of a superconductor material (Yttrium Barium Copper Oxide or YBCO) and to quantitatively investigate the dependence of its resistivity on temperature, above the transition temperature.
For comparison also see video at:
http://www.youtube.com/user/MOSEMwp7#p/u/44/4rP3VO1CCVc

Apparatus: from the kit you will need

- the YBCO sample in its Al container and connection cable – no.1;
- the USB interface with a cable for the measurement – no.14 and 15.

Moreover you will need:
- a thermally insulated container (Dewar or Styrofoam cup) – no. 1;
- liquid nitrogen;
- a PC with the USB acquisition system (CD provided with the kit) installed.

Fig. 4.1.2A Experimental set-up components.

Procedure:

Acquire the temperature and the resistance of the YBCO sample, while it is heating from below the critical temperature for superconductivity to approximately 100K. Determine the critical temperature of the superconducting phase of the material.

1. What graph will come out? Draw a draft. Mind the axis!

Connect the sample to the USB interface and the interface to the computer. Start the acquisition program and setup the correct gain for the acquisition by selecting the “Superconductor” option in the drop-down menu situated in the upper part of the screen.

Press START button in the left part of the command bottom bar. In the pop-up menu that appears, make sure that the option “Enable Temperature Driving” is deselected, and press OK.

On the right part of the window, a table will start to be filled with the values of temperature (in kelvins) and resistance (in mohms) of the sample. These values must be stable, respectively around room temperature (about 300K) and a few mΩ. Left to the table there is a graphical display of the relation between resistance (vertical axis) and temperature (horizontal axis): it must show a blur spot, confirming the steady state of the sample

Pour the liquid nitrogen into the Dewar or the Styrofoam cup (the help of the teacher or of a technician is required) and dip in it the container with the sample.
Observe the evolution of the temperature and resistance values, until a new steady state is reached, near 80K and 0 mΩ.
When the steady state is reached, press the “Stop” button in the command bar.

2. What did you observe?

When you are ready to start the actual measurement, press the “Start” button.
In the pop-up menu select the option “Enable Temperature Driving”, that enables the heating system of the sample. Choose the values for the final temperature in the measurement (typically well above 100K) and the temperature interval between two consecutive samplings (typical value 1K). When ready, press “OK”.
Observe the evolution of the temperature and resistance values, until the sample reaches the final temperature and the acquisition automatically stops.
Save on file the data acquired (button “Save”) and export them into a text format on another file (button “Export”).

3. Can you explain your observations?

Start a worksheet program (i.e. Excel) and open the text file with the exported data. Build a scatter plot graph of the resistance against temperature. Determine the interval of data points in which the resistance increases rapidly and almost linearly.
Build a second scatter plot graph of resistance against temperature, for the data contained in the previously selected interval, and add a linear trend line to the points.
Determine the intersection of the trend line with the horizontal axis and report the value of temperature associated as your estimation of the critical temperature.

Explanation Sheet

1. The USB interface enables acquisition of values of temperature (from a PT100 temperature sensor) and resistance (by means of a four point measurement) of the YBCO sample. The acquisition system can be used for resistance measurement of different materials, with different ranges of values for the electrical quantities. Because of this fact, the amplification of the ADC must be adjusted to fit the accuracy needed for the measurement, by selecting the appropriate measurement channel.
In the phase 1 of the experience students must familiarize with the program interface, in particular with the tabular and graphical representation of the data acquired.

2. The boiling temperature for liquid nitrogen at atmospheric pressure is 77K, well below the critical temperature of YBCO.
In this phase students can observe the decrease of the resistance of the sample, as the temperature decreases, till the rapid drop at the critical temperature and reaching a steady state at a temperature near to the boiling point of nitrogen.
The transition to the superconducting status is not sharp, but it presents a rapid but smooth decrease of the resistance within a temperature interval of few kelvins. In this phase, data for the correlation between resistance and temperature are taken out of thermal equilibrium and are affected by the thermal inertia of the experimental setup. Due to this reasons, it is suggested to discard such data in the analysis.
The final steady state of the sample can be not exactly at the temperature of 77K, because the connection cables (and eventually the part of the container not dipped in the liquid nitrogen) make a thermal contact with the external environment.

3. The heating system (enabled by the option “Enable Temperature Driving”) consists of a resistor inserted in the support of the sample and powered directly by the USB interface. The heater is powered cyclically, till the temperature increases to a desired value (start value plus the step) and then powered off. When the temperature temporarily stabilizes and the sample is almost at thermal equilibrium, the resistance is measured; then the procedure is repeated up to the maximum temperature chosen.
The typical duration of the experiment is about 45 minutes.

4. The scatter plot graph R vs T shows three different behaviours.
Below the critical temperature, the resistance is equal to zero, showing the superconducting status of the sample. Well above the critical temperature, resistance varies smoothly, typically with a linear dependence on temperature. At the transition, the resistance increases rapidly, starting from the critical temperature of the sample. The intercept of a straight line fitted to the points in this region gives a good estimation of this temperature.
The critical temperature depends on the composition of the material. The superconducting property of $YBa_2Cu_3O_{7-x}$ is sensitive to the value of x, its oxygen content. Only those materials with $0 \le x \le 0.6$ are superconducting below T_c, which depends on x and is the highest one, $T_c = 92$ K, when $x \sim 0$.
The extension of the transition region depends on the homogeneity of the material and the defects in the lattice of the crystal. Experimental studies show that the sintering process used to produce it deeply affects the extension of this region.

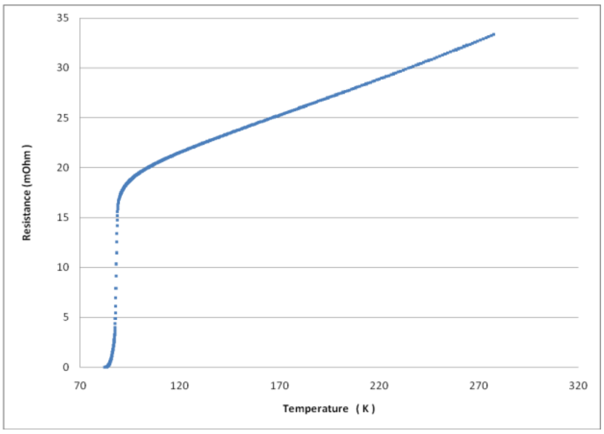


Fig. 4.1.2B Dependence of YBaCuO resistivity on

4.1.4 What is the temperature of Liquid Nitrogen?

Setup

Necessary equipment: Half a litre of liquid nitrogen, liquid nitrogen container; thermocouple; calibration table for thermocouple K; voltmeter.

Pour liquid nitrogen into the container. Plug the thermocouple in the voltmeter; use the smallest DC voltage range. Do not use the temperature range: the temperature range of the voltmeter allows the user to read directly the temperature in °C but not down to liquid nitrogen temperature.

Hints

The white fumes are not nitrogen (it is transparent, 80% of atmosphere is nitrogen), but it is water moisture from the atmosphere condensing in the cold vapour of nitrogen gas. The droplets of liquid nitrogen run without friction on the table because of a cushion of nitrogen gas between the droplet and the table. A similar effect happens when a water drop falls on a hot plate.

Observations

- Check the voltage value in the thermocouple at room temperature. Look at the table and understand how to use it.
- Dip the thermocouple extremity in liquid nitrogen.
- What are your observations?
- What is the temperature of liquid nitrogen?

Minds-on questions

Why is liquid 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?

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.

First, let the students realize that the voltage across the thermocouple is zero at room temperature, and that a voltage appears when the temperature is increased (by warming up the extremity of the thermocouple with your hand, or using a small hairdryer).

Then, give them the table, and let them try to understand it. Emphasize that a thermocouple measures a difference of temperature (more precisely, a difference of voltage), and that the table needs a reference temperature, which is traditionally set at 0°C. This is why in this table a zero voltage means 0°C. Lead the students toward the correction needed to obtain the correct temperature: the voltage corresponding to the temperature of the thermocouple extremities (room temperature, around 0.8 mV according to the table) should be added to the voltage reading before using the table to obtain the temperature.

The physics of the experiment

A thermocouple is based on a property of matter, the Seebeck effect: when a gradient of temperature is applied to a metal, a difference of electrical potential appears. The reason for this is that a transfer of heat (due to the temperature gradient) also implies a transfer of charges. One can demonstrate the following: this voltage only depends on the temperature of the extremities, and the nature of the metal (see Fig. 4.1.4-a). The intermediate temperatures across the metal do not influence this voltage. As a result, if two wires of different metals (with different Seebeck effects) are connected in one point, and if this point is at a temperature different from the extremities (say, because it dips in liquid nitrogen), a voltage will appear, that will only depends on the type of the metals, the temperature of the extremities (room temperature, ~ 20 °C), and the temperature of the junction. This is called a thermocouple, and is used a lot in industry to measure temperature (for example the temperature in industrial ovens). Unlike the Pt100 (used in the activities 4.1.1 and 4.1.2), a thermocouple measures a difference of temperatures, not the temperature directly: the temperature of the extremities must be known, or evaluated. Various technical information concerning thermocouples can be found on the following site: www.omega.com

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, about -196°C (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 represents 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. If you could pump the air above the liquid nitrogen, its temperature would decrease, and the liquid would eventually transform in a solid (nitrogen ice cubes!).

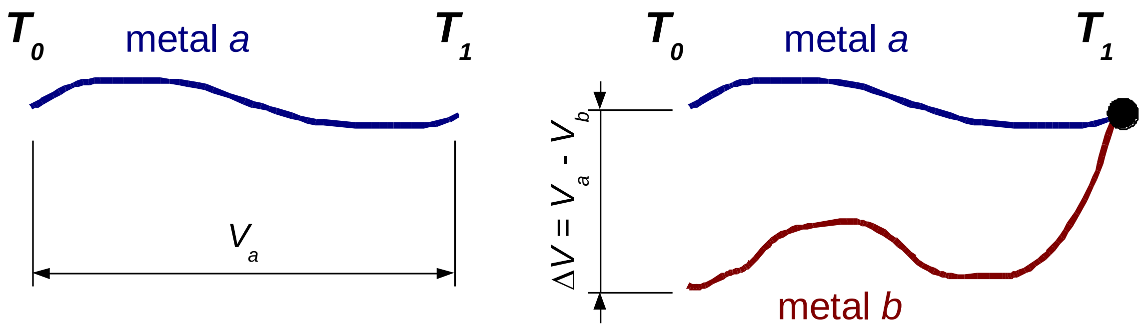


Fig. 4.1.4A Left: a voltage appears when a difference of temperature is applied at the extremities of a wire. Right: when two different metals are soldered at one extremity, the difference of temperatures makes a voltage ΔV appear between the free extremities of the thermocouple. This voltage depends only on T_1, T_0 and the nature of the metals a and b. Standard thermocouples have been calibrated and are regularly used in industrial application.

4.1.5 The leaking beaker

Setup

Necessary equipment: A plastic beaker, an aluminum foil, a strong magnet, matches.
Cut the bottom of the plastic beaker, approximately 3 cm below the top. Keep the upper rim. It will be used to hold safely the aluminum beaker.

Hints

To make the aluminum beaker, you can shape the aluminum foil on the plastic beaker.

Observations

Make a beaker from the aluminum foil, fixing the rim to the cut top of the plastic beaker, in order to provide a safe way to hold it. Holding the aluminum beaker, pour some liquid nitrogen into it, till it is half full. Some drops of liquid, falling down should appear after a while. Bring a strong magnet close to the falling drops. Let a drop fall on an ignited match.

Pedagogy

Let the students investigate the origin of the liquid. Let them look for a leak in the beaker, either by looking carefully at it, or by pouring some water in it (after removing the liquid nitrogen).

Minds-on questions

What is the reason the liquid drips from the beaker?

What substance is flammable and paramagnetic?

The physics of the experiment

Liquid nitrogen boiling temperature is 77 K, and liquid oxygen boiling temperature is around 90 K. When liquid nitrogen is poured into the aluminum beaker, it is cooled down below 90 K, even on the outside of it (aluminum is a very good thermal conductor, and the foil is very thin). The oxygen from the air will liquefy on the cold surface of the beaker, and some drops will fall. The beaker is not leaking, the liquid comes from the air…
Liquid oxygen is paramagnetic, it will be attracted by a magnet. It is also flammable, if a drop falls on a burning match, the flame will flare.
Liquid oxygen can also be observed during the levitation experiments: drops of liquid oxygen will condensate on the superconducting pellet, and will be attracted to the magnet: sometimes one can observe a drop jumping from the pellet to the magnet.

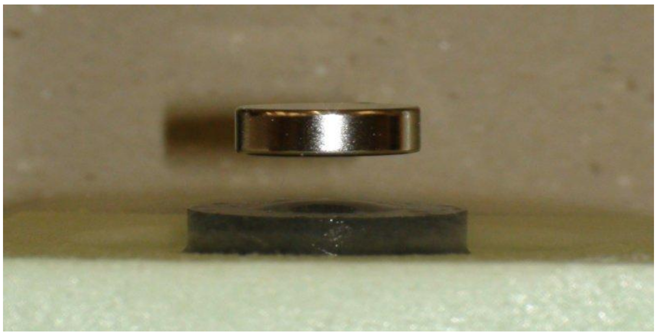


Figure 4.1.5A The liquid oxygen drop can be seen in the levitation experiment. The drop is located just below the magnet because it is attracted by it. If the magnet is brought closer to the surface of the pellet, the drop will jump up to it.

4.2 Persistence of current

4.2.1 Demonstration of persistence of current in a superconducting ring

Student Worksheet

Safety Issues:

Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor.

Aim: to demonstrate the persistence of an induced current in a superconducting ring.

Apparatus: from the kit you will need
superconducting ring(s) – no.6.7;
strong magnet – no.25;
iron rod – no.6.10;
Hall probe – no.13;
plastic tweezers – no.6.2;
bowl – no.9;
liquid nitrogen.

Fig. 4.2.1A Experimental set-up components.

Place the cup on a suitable stand so that the Hall probe can be placed underneath it.
Set up the rod, magnet and solid ring as shown in fig. 4.2.1B

Place the Hall probe under the cup and take a reading from the Hall probe meter. This is the field induced by the magnet.
Carefully pour liquid nitrogen into and wait for the boiling to stop.
Now remove the rod and magnet from the ring and look at the Hall probe meter.

1. What do you notice?

Move the cup away from the hall probe.

2. What do you notice?

Return the cup to its original position and using the tweezers carefully turn the ring over.

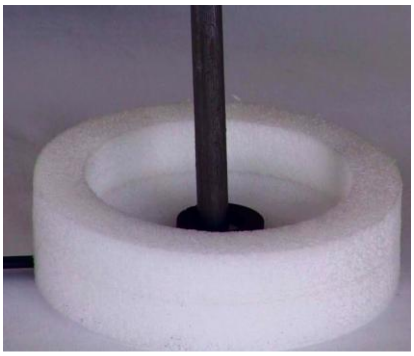


Fig. 4.2.1B Metal rod with the magnet attached inserted into superconducting ring.

3. What do you notice?

Now repeat the investigation using the split ring

4. What do you notice?
5. Can you explain your observations?

Explanation Sheet

1. When the rod and magnet are removed from the ring a field is still detected by the Hall probe.

2. As the cup, with the superconducting ring, is moved away from the Hall probe the reading effectively drops to zero.

3. When the ring is turned over ideally the sign of the field changes. However it may happen that you observe a change in value only.

4. Ideally you should not observe an induced magnetic field but it is likely that you will observe a field of reduced value.

5. A changing magnetic field creates an electric field; this phenomenon is described by the Faraday equation. The induced electromotive force (EMF) in any closed circuit is equal to the time rate of change of the magnetic flux through the circuit; EMF is expressed in volts while the magnetic flux in webers. In practice, this means that an electrical current will be induced in any closed circuit when the magnetic flux through a surface bounded by the conductor changes. This applies whether the field itself changes in strength or the conductor is moved through it.

When the magnet and the rod are in the center of the ring in its ”normal” state, then the external field produced by the magnet passes through the ring and a certain magnetic flux is trapped there. When the ring is cooled down with liquid nitrogen, it undergoes a transition to the superconducting state with zero resistance. Then, when the magnet is removed, the flux changes and, according to Lenz's law, the EMF induced in the loop by this changing flux produces a current that sets up its own magnetic field opposing the change. Since the flux does not vary with time the current also remains constant. This persistent current is the result of a quantum mechanical effect that influences how electrons travel through metals in the superconducting state, and arises from the same kind of motion that allows the electrons inside an atom to orbit the nucleus forever. The induced current is a loop around the ring and hence when the ring is turned over the field will have the opposite sign.

Taking things further

The scope of this demonstration can be extended by attaching the Hall-probe to a Vernier microscope scale. Using such a set up the field strength at a distance from the centre of the ring can be measured. The averaged results of three runs are shown on the right.

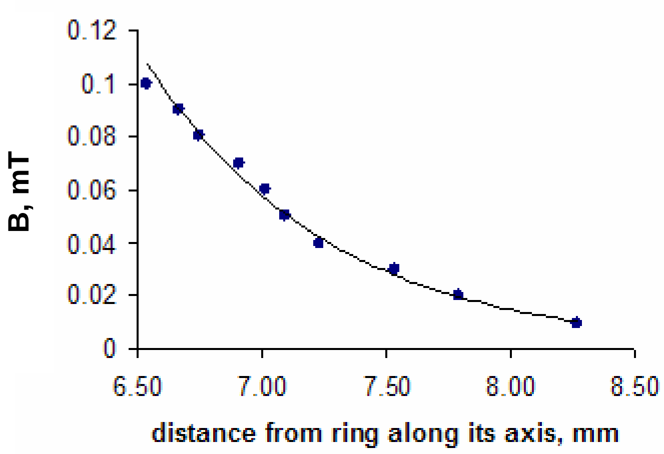


Fig. 4.2.1C Magnetic field at certain distances from ring’s axis.

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 minimized 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 please ask your local safety advisor.

Aim: to investigate the magnetic properties of a superconductor.
See video at: http://www.youtube.com/user/MOSEMwp7#p/u/1/fx2DJLTyUuk

Apparatus: from the kit you will need
Meissner pellet – no.6.7;
thin disk magnet – no.26;
plastic tweezers – no.6.2;
foam cup – no.9;
liquid nitrogen.

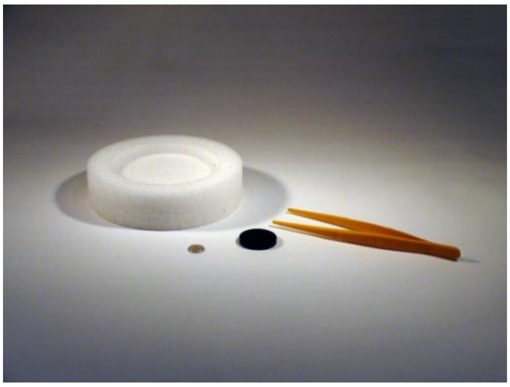


Fig. 4.3.1A Experimental set-up components.

Procedure:
Place the magnet on the Meissner 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 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?

Explanation Sheet

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

2. As the temperature is reduced by 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 ejects the magnetic field produced by the magnet.

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

4. The role of this experiment is to demonstrate the Meissner effect. Even though all the pellets are made from the same superconductor, only the labeled “Meissner” pellet will demonstrate it, as explained in the experiment 4.3.2 and 4.3.3 (the Meissner pellet is a superconductor with low pinning ability).

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 in this case), inside its bulk. An alternative cooling procedure, known as zero field cooled experiment, consists in cooling the superconductor without a magnetic field and introducing the field, below the critical temperature, by bringing the magnet close to the pellet. With the pellet used in this investigation both procedures would give the same final result but only the field cooled experiment demonstrates the expulsion of flux or the Meissner effect: the flux was present at the beginning of the experiment, but it was ejected when the temperature fell below 92 K.

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

In order to eject the magnetic field from its interior, the superconductor sample develops currents on its surface; since it is a superconductor, these currents cause no heat energy dissipation (no Joule effect). These currents create within the bulk of the sample a magnetic field that exactly opposes the applied external field. The net field is therefore zero in the bulk of the superconductor. The surface currents effectively form an electromagnet that repels 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 screening 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.

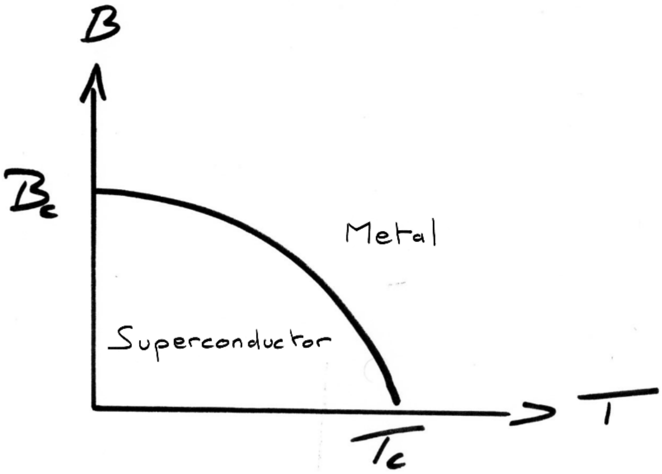


Fig. 4.3.1B Phase diagram, illustrating the conditions of existence of superconductivity in a metal: superconductivity exists only below a given temperature (T_c), and magnetic field (B_c).

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 eject 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 eject it.

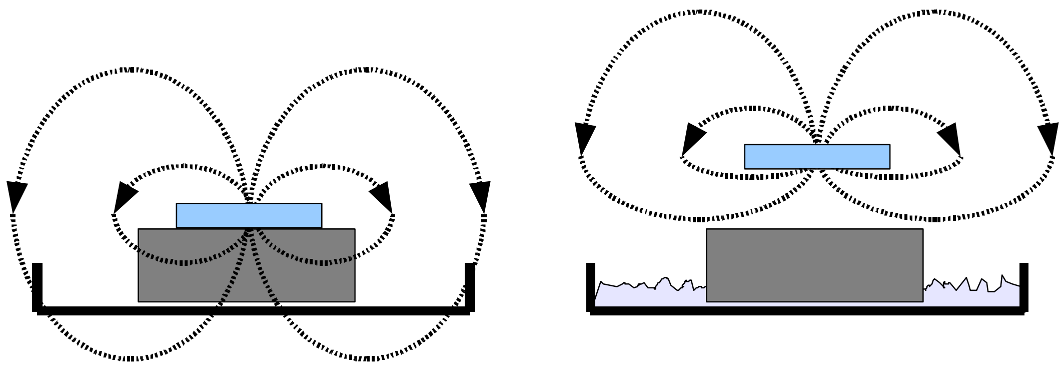


Fig. 4.3.1C On the left, a warm superconductor (in gray), with a magnet on the top (in blue). The dashed lines represent the magnetic field lines of the magnet. Since the pellet is warm, it behaves as a normal metal, and the magnetic flux can penetrate. On the right, the pellet has been cooled down by liquid nitrogen and is now superconducting. It now ejects the magnetic field lines, and creates a force that makes the magnet to levitate (Meissner effect).

The reason a superconductor cannot coexist with a magnetic field is directly rooted in 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.
Meissner effect is the main cause of the levitation, but if it were the only one, the levitation should not be stable. The expulsion of the flux should expel the magnet, which it does, but the magnet should be pushed aside 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 existing nevertheless. Actually, there are two types of superconductors: type I, that behaves as explained above, and type II, that have a more complex behaviour, responsible for the existence of the "link". The superconductor used here is of the type II. The following experiments demonstrate the nature of this "link", which is due to a partial pinning of the magnetic flux.

Additional Comment

A real Meissner levitation is difficult to be observed. To do so, you need to use a type I superconductor, to be sure that no vortex exists (see the teacher guide or the following experiments). Unfortunately, no type I superconductor has a T_c above 20 K, so liquid helium, with a vaporization temperature of 4.2 K, should be used instead of liquid nitrogen (with a vaporization temperature of 77 K).

A simple experiment can be used to demonstrate that a pure Meissner effect should allow the levitation. To allow a stable levitation of a magnet over a type I superconductor, the sample has to be of bowl shape (see figure 4.3.1D). This experiment was realized by Arkadiev in 1947 using lead, which is a type I superconductor with a critical temperature slightly above 7 K. This was the first superconducting levitation experiment.

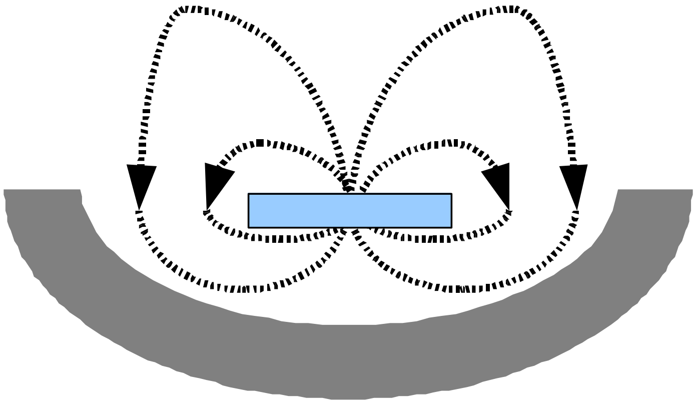


Fig. 4.3.1D A bowl made of lead, cooled down below 7.4 K, becomes a type I superconductor. A magnet in this bowl will levitate and the shape of the superconductor will prevent the magnet from gliding over the side. To cool down the lead bowl, liquid helium, instead of liquid nitrogen, is used. Liquid helium is cooler (4.2 K under ambient pressure), but is more expensive and is more difficult to manipulate. See *A floating magnet*, by V. Arkadiev, Nature 160, 330 (1947).

4.3.2 Levitation: Meissner levitation and pinning compared

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor.

Aim: to study the properties of two YBCO superconductors.

Apparatus: from the kit you will need
Meissner pellet – no.6.7;
strong pinning pellet – no.6.6;
thin disk magnet – no.26;
plastic tweezers – no.6.2;
thin spacer – no.22;
foam cup – no.9;
liquid nitrogen.

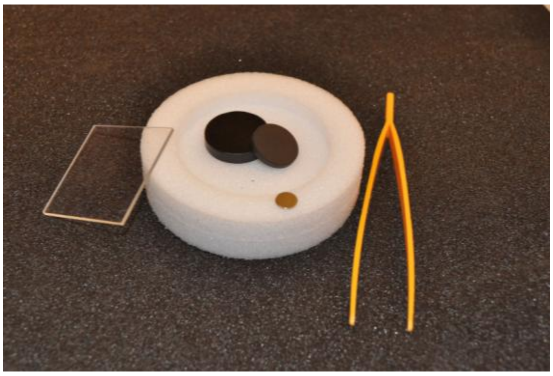


Fig. 4.3.2A Experimental set-up components.

Place the Meissner pellet in the cup, place the spacer on the pellet and the magnet on the spacer. Pour liquid nitrogen into the cup and wait for the boiling to stop. Now remove the spacer, the pellet should levitate as in the Meissner levitation investigation.

Without allowing the pellet to warm up try to flip the magnet over, reversing the direction of the field, use the tweezers not your fingers.

1. What do you notice?

Try to push the magnet sideways, using the tweezers.

2. What do you notice?

Repeat the investigation using the strong pinning pellet.

3. What do you notice?

4. Can you explain your observations?

Explanation Sheet

1. If done carefully, it is possible to reverse the polarity of the magnet without breaking the levitation. To do so, you may have to push the magnet close to the superconducting pellet, as if to plant it in a sandbox. This is compatible with the Meissner explanation of the levitation, since the Meissner effect is the expulsion of the magnetic field, whichever pole it originates from. However, the levitation is not supposed to be stable if the Meissner effect is the only cause of the levitation (see experiment 4.3.1).

2. If the magnet is gently pushed, it will return to its original position, if pushed too hard, it will fall. If the pellet is pushed, the magnet will follow its movement demonstrating a weak magnetic link between the magnet and the pellet. This link, however weak, is not accounted for by the Meissner effect. This link is responsible for the stability of the levitation.

3. The magnet does not seems to levitate as the pellet becomes superconducting, it remains on the spacer. But when the spacer is removed, it stays at the same position, levitating at 1.5 mm above the pellet. It is impossible to flip the magnet; it will jump back to its original position (you may have to paint one face of the magnet to differentiate the poles). It is very difficult to move the magnet and a large force is needed, the pellet will follow the magnet. If the pellet is moved the magnet follows.

4. These observations demonstrate that there is now a strong magnetic link between the magnet and the pellet. In some cases it is even possible to lift the pellet by raising the magnet, remember to use the tweezers.
These experiments are a demonstration of the “magnetic link” that exists between the magnet and the superconductor.

It is interesting to observe the difference between the strong pinning and the Meissner effect. The fact that the magnet stays close to the superconductors shows that the magnetic field that is around the magnet passes through the superconducting pellet, which is in contradiction with the magnetic flux expulsion. The only way to explain this observation is to consider that the magnetic field of the magnet is “frozen” inside the superconducting pellet. When one tries to remove the magnet, the “frozen magnetic field lines” produce a strong force to keep the magnet in place, since moving the magnet corresponds to moving the magnetic field.

This link exists in both pellets, but in the strong pinning pellet, the “link” is so strong that it hides the Meissner effect. Indeed, in the so called “Meissner pellet”, the pinning also exists, (which means that it is not a pure demonstration of Meissner effect), but is very weak. Still, the existence of this pinning provides stability to the levitation by providing a small “link” between the pellet and the magnet, preventing the magnet from gliding off the side. The Meissner effect alone does not allow a stable levitation for this shape of pellet.

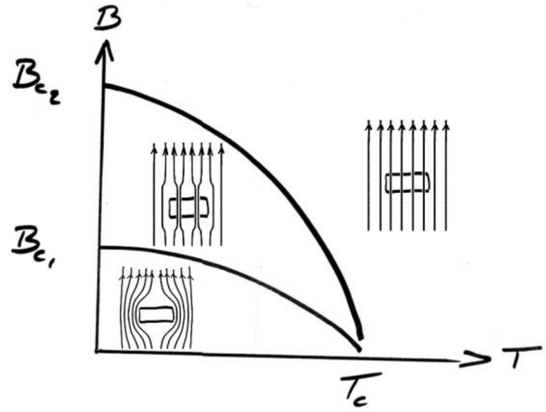


Fig. 4.3.2B Phase diagram, illustrating the conditions of existence of superconductivity in a type II superconductor: Meissner effect exists only below a given temperature (T_c), and magnetic field (B_{c1}). Above a second critical field B_{c2}, superconductivity is destroyed. Between B_{c1} and B_{c2} the superconductor is in the mixed state, with vortices carrying a flux quanta and a non-superconducting core going through. The physics of vortices is explained in the teacher guide.

Actually, there are two types of superconductors: type I superconductor, where superconductivity can only exists in the Meissner state, with no magnetic field present in the bulk of the pellet, and type II, that have a behaviour that is more complex. This behaviour is responsible for the existence of the “link”. The link is due to the presence of vortices trapped in the superconductor: they are the “frozen” field. The superconductor used here is of the type II.

4.3.3 Levitation: testing the pinning

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor.

Aim: to investigate the pinning properties of a YBCO superconductor.

Apparatus: from the kit you will need
strong pinning pellet – no.6.6;
thick disc magnet – no.25;
plastic tweezers – no.6.2;
medium spacer – no.23;
gaussmeter – no.13;
liquid nitrogen.

Fig. 4.3.3A Experimental set-up components.

Place the pellet in the cup, place the spacer on the pellet and the magnet on the spacer. Pour liquid nitrogen into the cup and wait for the boiling to stop. Now remove the spacer.

1. What do you notice?

Without allowing the pellet to warm up try to flip the magnet over, reversing the direction of the field, use the tweezers not your fingers. Take the magnet out, and try to bring it back in a reversed position.

2. What do you notice?

Try to spin the magnet using the tweezers.

3. What do you notice?

With the tweezers, remove the magnet from its position and put it away from the superconductor (be careful where you put it – it is a strong magnet). With the gaussmeter, compare the magnetic field at the surface of the superconductor, and above the magnet (use the spacer to measure the field 4 mm above the magnet).

4. What do you notice?

Allow the pellet to warm up a little. To speed the procedure, the liquid nitrogen can be removed from the cup, or the pellet can be taken out of the cup. When the magnet is not levitating anymore, take the magnet away, and cool the superconductor again, without any magnet. Wait for the boiling to stop. Measure the magnetic flux at the surface of the superconductor, and then try to make the magnet levitate.

5. What do you notice?

Explanation Sheet

1. The magnet, even if bigger then in experiment 4.3.2, behaves as if stuck in place. This proves that there is a strong, magnetic, link between the magnet and the pellet. The force of the link can be felt when trying to remove the magnet from its position.

2. Reversing the polarity of the magnet causes it to “flip” back to its original position, even if the magnet is taken away and brought back. It may be necessary to mark one side of the magnet to differentiate the poles.

3. However, as it is a round magnet, the magnetic field will not be altered when the magnet rotates and hence it will spin freely. A rectangular magnet would not be allowed to spin (see experiment 4.3.4).

4. The magnet is taken away, but there is a magnetic flux at the surface of the magnet. The value measured by the gaussmeter is very close to that measured at a few millimeters from the surface of the magnet (the thickness of the spacer): the flux that was present in the pellet when it became superconductor was trapped, and remains within even if the magnet is taken away. (Another way to visualize the frozen flux is to show that paper clips are now attracted by the superconductor as if it were a magnet – which we know a superconductor is not.)

5. When cooled away from any magnet, no flux is pinned. When a magnet is brought close to the superconductor it is repelled since no magnetic field was trapped. The repulsion is quite strong and a large force is needed to approach close to the pellet.

A first step analysis: All of these investigations can be understood in term of “frozen” or pinned magnetic field: when the pellet becomes superconducting, it freezes the magnetic field that is present inside its bulk at the transition time. This “frozen magnetic field” creates a sort of “magnetic image” of the magnet; at the position the magnet was when the pellet became superconductor. This magnetic image corresponds to a position of equilibrium for the magnet, since its magnetic field matches that which is frozen. A force is needed to take it out of this equilibrium position, and if its weight is not enough to provide this force, then the magnet levitates. By pulling or pushing the magnet, you can feel the force that is needed to take the magnet away. Up or down make no difference, but the polarity of the magnet does; if you reverse the polarity of the magnet, you no longer have a match. The frozen “magnetic field” is clearly demonstrated by the gaussmeter as the magnet is removed.

The “frozen magnetic field” is another way of saying that the superconductor will fight a change of magnetic field.

In a zero field cooled procedure, no magnetic field is present in the pellet as it becomes superconducting. No magnetic field is frozen. If a magnet is brought near the pellet, it will be repelled: in a way, we can consider that there is a frozen magnetic field, but that this frozen magnetic field is a null magnetic field. Trying to bring a magnet near will be resisted as this would change the null field. Note that this effect is not the Meissner effect: the magnetic field originating from the magnet is strong enough to be over B_{c1} and penetrate the sample as vortex (mixed state). The effect observed here is that the magnetic field cannot move easily in or out of the sample.

If one pushes the magnet hard enough, some magnetic field will be pushed inside the pellet, where it will be frozen: the magnet then levitates.

Quantitative analysis: There are two types of superconductors: type I superconductor and type II.

Type I superconductors manifest only the Meissner phase. If the temperature is below a critical temperature T_c, and if the magnetic field is below a critical field B_c, then the pellet becomes superconductor. This is a true phase transition of the electrons in the material; the system is in thermodynamic equilibrium, which means that the system has no memory of what happened before, only the current temperature and field values matter. Lead is an example of type I superconductor, with a T_c of 7 K at zero field, and a critical field of 0.08 T, mercury is also a type I superconductor, with a T_c of 4.2 K and a B_c of 0.04 T.

Type II superconductors exhibit two critical fields. Below the lower critical field B_{c1}, they behave as type I superconductors. Above the upper critical field B_{c2}, they are normal metals. But between B_{c1} and B_{c2} they exhibit a strange phase, so called "mixed state", or "Abrikosov phase". This phase corresponds to a superconducting phase with some "tunnels" of normal state, those are regions where the material stops being a superconductor, allowing the magnetic field lines to go through the material. These tunnels are called "vortices", and they have the property of carrying a single quantum of magnetic flux ϕ_0. These vortices are strange beasts, since their size is rather macroscopic, their cores vary from 1 to 100 nanometres (10 to 1000 angstroms), depending on the superconductor, but nevertheless their nature is a quantum one.

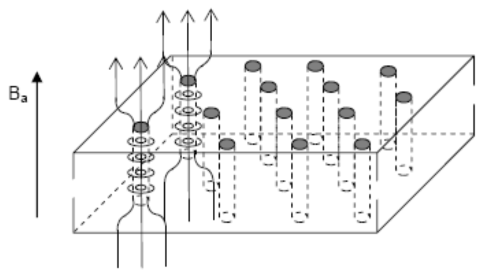


Fig. 4.3.3B Concept of vortices.

The vortices are an important concept in the explanation of superconductivity but they are not easy to understand.

A consequence of these vortices is that the superconductor is no longer a perfect diamagnetic material, since some flux lines pass through it. Actually, it is still a diamagnetic material: its magnetic susceptibility is still negative but it goes rapidly toward zero when the external field is increased, i.e. as more vortices enter.

In theory, the number of vortices present in a superconductor depends only on temperature and external magnetic field, since the number of vortices should be the result of the balance of the "magnetic pressure" and the superconducting strength. However, it is important to realize that this approach assumes that the system reaches its equilibrium, which means that the system can reach the most favourable state for the given external conditions. In such a description, the previous history of temperature and magnetic field should play no role. The striking difference of behaviour observed between a zero field cooled and a field cooled experiment demonstrates that the system has some kind of "memory" of its history: this is known as an "irreversible effect", or "out-of-equilibrium physics". The system is prevented from reaching its most stable configuration, and is stuck in a metastable configuration: there is an energy barrier to cross in order to reach the most stable configuration, and the system is trapped out of it. A classical example of out of equilibrium physics is the over-cooled water, i.e. water which is still liquid below 0^oC whereas its "natural" state at such temperature is ice.

In the case of the vortices, what happens is that the vortices can easily be pinned in the material, depending on its quality. Thermal and magnetic equilibrium would require the vortices to easily enter or leave the superconductor to reach the most stable configuration, but since the vortices are pinned, they can not move anymore: the magnetic flux they carry becomes frozen. This is the physical origin of the "frozen magnetic field" that was demonstrated by these experiments: in the case of field cooled experiments, the magnetic field of the magnet in the pellet becomes contained in the vortex cores, and then trapped. On the other hand, in a zero field cooled experiment, when a magnet is brought closer, the repulsive force corresponds to the force needed to push vortices into the pellet.

So, the difference between the Meissner pellet and the strong pinning pellet is that the strong pinning pellet provides strong pinning of the vortices, whereas the Meissner pellet does not. These two pellets have the same chemical formula ($YBa_2Cu_3O_7$), but the quality of the crystals is different. Here, both pellets are polycrystalline, but the Meissner pellet has a random orientation of the grains, whereas in the strong pinning pellet, the grains are oriented along their main direction, a textured sample: the orientation of the grains gives larger critical currents and this helps with the pinning of the vortices.

The following article discusses the levitation of a magnet over a strong pinning superconductor:
Rigid levitation and suspension of high-temperature superconductors by magnets, by E. H. Brandt, Am. J. Phys. 58, 43 (1989)

4.3.4 The inverted levitation

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor.

Aim: to investigate the pinning properties of a YBCO superconductor.
See video at: http://www.youtube.com/user/MOSEMwp7#p/u/0/gyiXPwQbioU

Apparatus: from the kit you will need
strong pinning pellet – no.6.6;
rectangular magnet – no.27;
plastic tweezers – no.6.2;
thin spacer – no.22;
paper clip tweezers – no.6.12;
clear plastic beaker – no.8;
liquid nitrogen.

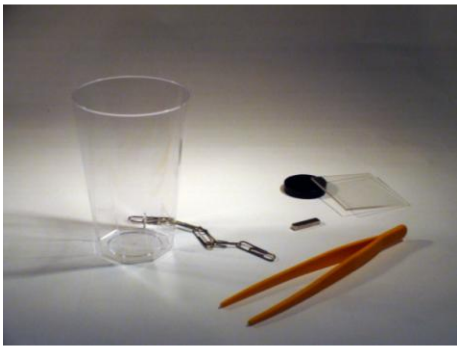


Fig. 4.3.4A Experimental set-up components.

Place the pellet in the clear plastic beaker. Then place the beaker on the spacer on top of the rectangular magnet. Fill half the beaker with liquid nitrogen and allow the boiling to stop. Now remove the spacer and lift the beaker.

1. What do you notice?

Without allowing the pellet to warm up try to flip the magnet over, reversing the direction of the field, use the tweezers not your fingers. Take away the magnet and try to replace it.

2. What do you notice?

Try to spin the magnet using the tweezers.

3. What do you notice?

Take away the magnet and bring the paperclip close to the bottom of the beaker.

4. What do you notice?

Allow the pellet to warm up a little. To speed the procedure, the liquid nitrogen can be removed from the beaker, or the pellet can be taken out of the liquid nitrogen. Cool the superconductor again, without any magnet close by. Wait for the boiling to stop. Bring the paper clip close.

5. What do you notice?

Explanation Sheet

1. The magnet levitates, but it levitates below the superconducting pellet. It behaves as if stuck in place. This proves that there is a strong, magnetic link between the magnet and the pellet.

2. Reversing the polarity of the magnet causes it to "flip" back to its original position, even if the magnet is taken away and brought back. It may be necessary to mark one side of the magnet to differentiate the poles.

3. Rectangular magnet trying to spin will cause a large change in the field and hence it will either return to its original position or align itself at 180° to its original position where the field is the same. It is not possible to put it at 90° of its original position: the change of magnetic field would be maximal.

4. The paper clip is attracted to the superconductor, as if it were a magnet, which we know a superconductor is not. This shows that some magnetic field is trapped, or pinned, inside the superconducting pellet. This trapped flux is the cause of the strong magnetic link between the magnet and the superconductor. Another way of showing the trapped flux is to use a Hall probe.

5. In the pellet cooled away from any magnet, no flux is pinned, and the paper clip is not attracted to the superconductor. When a magnet is brought close to the superconductor it is repelled since no magnetic field was trapped. The repulsion is quite strong and a large force is needed to approach close to the pellet.

A first step analysis: This experiment is exactly the same as the experiment 4.3.3 testing the pinning, even if they appear to be different. The magnetic field present in the pellet as it becomes superconducting becomes frozen. As a result, the magnet feels a force that fights any change of its position, whether it is above or below the pellet. The paper clip is an easy way to visualize the frozen magnetic field that was trapped within the pellet. The physical explanation of experiment 4.3.3 testing the pinning explains in a similar fashion the results observed here.

4.3.5 Feeling the pinning at different heights

Setup

Necessary equipment: all the materials needed for experiment 4.3.3 (testing the pinning); magnetometer.
Use the pinning magnet.

Hints

For each different height, you need to follow a field cooled procedure. There is no need to warm the superconducting pellet up to room temperature, you should only be sure that it is no more a superconductor: take it out of the nitrogen bath and wait for the magnet to land. Two spacers can be used at the same time to reach different heights. With the 1.5, 4 and 8 mm spacers, heights of 0, 1.5, 4, 5.5, 8, 9.5, 12, and 13.5 mm can be obtained.

Observations

Use the various spacers to make the magnet levitate at different heights. At each position, let the students feel the pinning force by trying to move the magnet out of the superconductor.

At each position, when the magnet is taken out, record the value of the pinned magnetic field on the superconductor with the magnetometer.

How does the pinning force varies with height? (qualitative answer)

How does the value of the pinned flux varies with height? (quantitative answer)

Minds-on questions

What might be the nature of the “link” between the superconductor and the magnet?

The physics of the experiment

The physics is the same as described in activity 4.3.3.

4.3.6 Measuring the pinning at different heights

Setup

Necessary equipment: two plastic beakers, a superconducting pellet, magnets, liquid nitrogen. Not in the kit: a controlled height platform, scales.

The idea is to weight the force between a superconductor and a magnet. The magnet is on the scales, and the superconductor is in the plastic beaker on a platform, which height can be varied. To avoid the influence of the magnet's field on the scales, fix the magnet on the top of the second beaker turned upside-down.

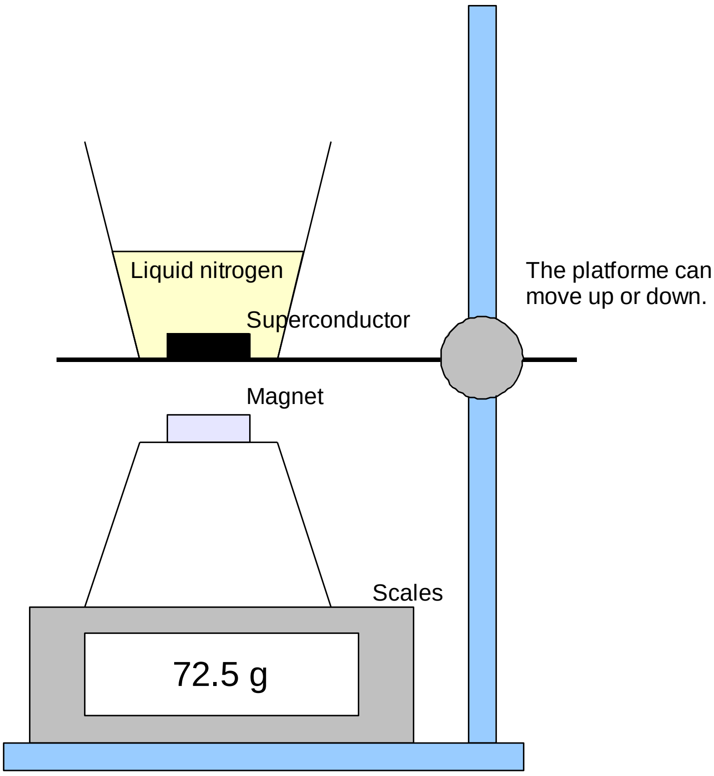


Figure 4.3.6A Sketch of the experimental set-up.

Hints

The scales indication for the Meissner superconductor is of the order of 10 g, while the indication for the strong pinning superconductor is of order of 1 kg, depending on the magnet that is used. If the force is too large, the magnet can be lifted of the scale, or the pellet can be repelled from the bottom of the beaker, depending on the nature of the force - attractive or repulsive (this depends on the cooling procedure). In such a case, heavy, non magnetic pieces (copper, plastic, ...) should be used in order to ballast the magnet or the pellet and prevent them from moving. When the Meissner pellet is used, the forces are small enough and no ballast is needed.

Observations

The force between the magnet and the superconductor is equal to the product of the scale reading and acceleration due to gravity, if the weights of the magnet and the beaker have been subtracted.

Different procedures can be tested: zero field cooled, field cooled, starting at different heights, difference between superconducting pellets.

Minds-on questions

What might be the nature of the “link” between the superconductor and the magnet?

The physics of the experiment

The physics is the same as described in activity 4.3.3.

This experiment and the physics behind it is described in detailed in the following article: *Measuring the interaction force between a high temperature superconductor and a permanent magnet*, by S. O. Valenzuela, G. A. Jorge, and E. Rodríguez, in American Journal of Physics -- November 1999 -- Volume 67, Issue 11, pp. 1001-1006.

4.3.7 Meissner versus diamagnetic levitation

Pedagogy

Begin with the question: "can a magnet levitate in a stable manner above a diamagnetic material?"
Let the students realize that the diamagnetism of the graphite is too weak to make such a heavy object as a magnet levitate.
Lead them to the conclusion that a "magnetic link" exists somehow in the Meissner case, and that this link is responsible for the stability of the levitation. This is connected with the activity 4.3.2, and is closely related to the activity 4.4.5.

Setup

Necessary equipment: all the materials needed for Meissner experiment 4.3.1, pinning magnet, pyrolytic graphite thin slab (wafer) ~ 10 x 10 mm^2.
Prepare the pyrolytic graphite slab beforehand, specially if the students are young. See the teacher guide for details on how to proceed. Do this activity after having performed the Meissner experiment 4.3.1.

Hints

Larger magnets than those in the experiment with Meissner levitation (Activity 4.3.1) can be used to try to make the wafer levitate, such as the magnet in the experiment with pinning (Activity 4.3.3).
To enable the students to feel the "link" between magnet and superconductor, let them use the tweezers to touch a bit the magnet (it will oscillate but not fall), or push the superconductors (the magnet will come with the superconductor): it is a stable levitation.

Observations

After having demonstrated the Meissner effect, try to do the same with the pyrolytic wafer.

Minds-on questions

Magnet over diamagnet, or diamagnet over magnet, is this the same?
What might be the nature of the "link" between the superconductor and the magnet?

The physics of the experiment

Since the diamagnetism of the graphite is far from being perfect the magnet is too heavy to levitate. If the locations of the graphite and the magnet are inverted the physics is exactly the same, let the students try to levitate the graphite over the magnet. The graphite slab will not levitate. If it is thin enough and a bit close to the edge, it will glide and fall.

The idea behind these experiments is that diamagnetism alone can not be the explanation for the stability of the levitation of the magnet over the superconductor. The reason for this is that the superconductor here is a type II superconductor, and that some magnetic flux is present in its bulk as vortices. These vortices are pinned, and provide the "magnetic link" that gives stability to the levitation. In this pellet, this effect is small enough that the Meissner effect can be seen (most of the flux has been expelled); in the strong pinning pellets used in activity 4.3.2, this pinning effect is so strong that the Meissner effect is hidden (the flux is not expelled because it is trapped).

4.3.7 The tilted magnet

Setup

Necessary equipment: all the materials needed for experiment 4.3.1 (the Meissner levitation), cubic magnets.

Hints

Once the importance of the poles has been recognized, use a small piece of gluing tape to indicate the direction of the poles; on a cubic magnet, the position of the poles is difficult to determine without some help.

Observations

Perform the experiment 4.3.1 using the cubic magnet instead of the thin disc.

When a cubic magnet levitates, it is easy to make it turn about any of its axis. Ask the students to make a levitation where the magnet turns about a vertical axis.

Ask the question: "why is the magnet tilted in the Meissner levitation experiment 4.3.1?"

Pedagogy

Let the students investigate why the cubic magnets sometimes levitate, sometimes glide aside. To help them, ask them why the cubic magnet is always rotating about an horizontal axis, and help them realize that this indicates that the poles are always horizontal. Ask them to try having a cubic magnet rotating about a vertical axis: they will not succeed (note that this is possible to realize with a strong pinning pellet, since the pinning traps the magnetic flux. This demonstrates that the MOSEM logo represents a strong pinning superconductor!).

To demonstrate that the force between the magnet and its image is stronger when the poles are arranged vertically, make the students feel the force between two real magnets, with poles parallel and poles aligned in a series, both in repulsive configuration. The difference can be felt easily.

Minds-on questions

What is the axis around which the levitating magnet rotates?
Is the MOSEM logo feasible?

The physics of the experiment

When trying to perform the experiment 4.3.1 with a cubic magnet, you observe that sometimes it levitates, sometimes it glides aside. It is because of the position of the poles.

One way to explain the levitation by the Meissner effect is to say that the currents in the superconductors (that are responsible for the flux expulsion) create a magnetic mirror image of the magnet; the interaction between the image and the real magnet is always repulsive, and so the magnet levitates, at the height where the magnetic force is compensated by the weight. The trick is that the force between the image and the magnet is stronger when the poles of the magnet are in vertical configuration, which means that the levitation height is higher. By flipping the poles vertically, the magnet reduces the force and lower its altitude, and thus gain some gravitational potential energy, which in a simple words means that things want to be as low as possible and fall down. When the magnet is of disc shape, the matter is a bit more complicated because a vertical disc is not mechanically stable, so the disc is tilted. By using a cubic magnet you can get rid of this additional mechanical effect. If you try to levitate a cubic magnet over a Meissner pellet, it will be impossible to have it with its poles vertical, it will always flip the poles horizontally.

Note that this explanation is a simplification of reality, since the levitation above the Meissner magnet is not purely a Meissner effect, there is a partial flux trapping, which explains the stability of the levitation (see activity 4.3.1).

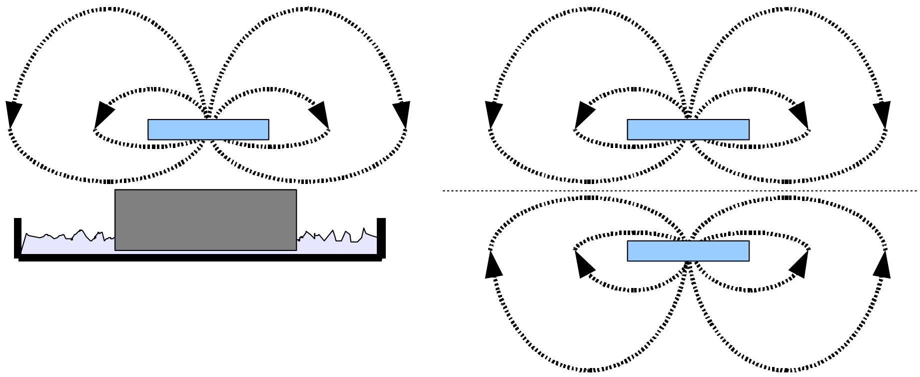


Figure 4.3.7A –The force exerted by the superconductor in a Meissner state on a magnet (left) is the same as that exerted by a virtual magnet, placed symmetrically to the surface of the superconductor (right). The superconductor behaves like a "magnetic mirror".

When the poles are horizontal, the magnet levitates above the Meissner pellet 1 mm lower than if the poles are arranged vertically (see figure 4.3.7-B). The difference in the levitation height between the horizontal and vertical poles configurations can be demonstrated by preventing the magnet to rotate 90 degree. This can be achieved for example by making a square shape tunnel, using two microscope slides and some foam bricks. The difference is even bigger if you use the strong pinning pellet after a zero field cooled procedure, which mimics the Meissner effect by expelling the magnetic flux from the pellet.

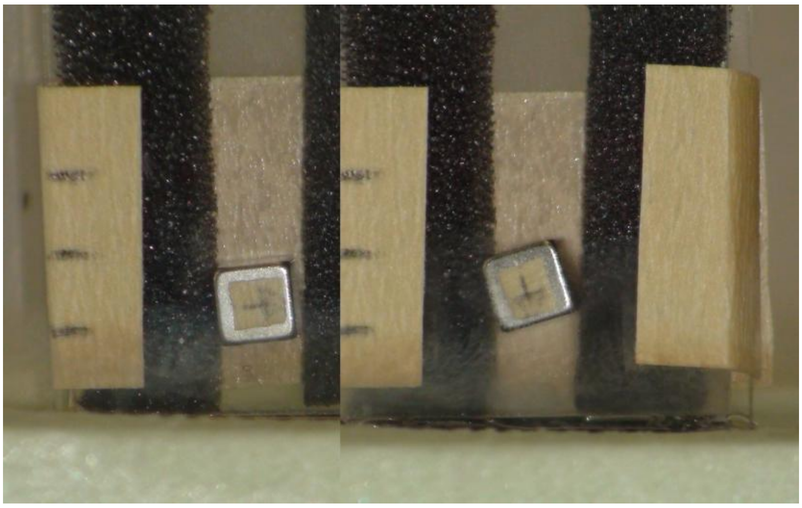


Figure 4.3.7B A cubic magnet levitating above a Meissner superconducting pellet, with their poles in horizontal (on the left) and with their poles in vertical (on the right) configurations. The arrow on the magnet represents the direction of the north pole. In the latter case, the magnet levitates one millimetre higher. This is unstable, and the magnet tend to flip its poles to reach the horizontal configuration, but the foam prevents the flipping.

4.3.9 Try to do that

Pedagogy

This is a recreational activity. Let the students test whatever idea they want to test.

Setup

Necessary equipment: All the equipment of the experiments 4.3 (levitation experiments).

Hints

You can let the students test various combinations of magnets. Small nails (ferromagnetic) could also be used.

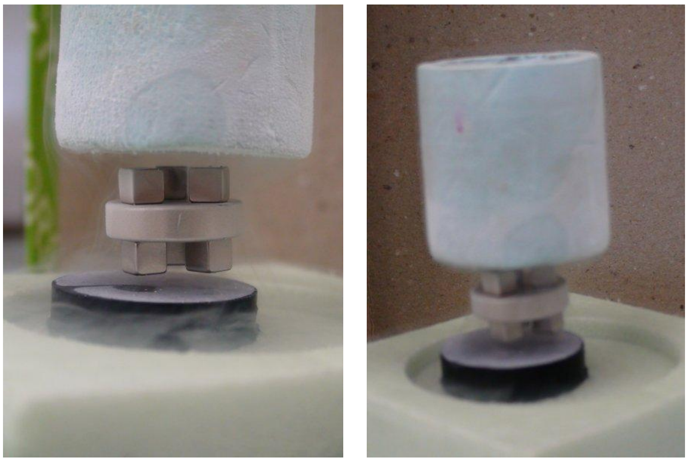


Figure 4.3.9A Try to do that…

Observations

Show the students the picture of the experiment with levitation (figure 4.3.9A), and ask them to try to repeat it.

When they have done so, ask them to propose their original levitation set-up. Take pictures of the most successful ones and send it to the media.mosem.no web site corresponding pages, where they might get published.

The physics of the experiment

The physics here is that of the experiments of superconducting levitation 4.3. The aim is to enable the students to carry out the experiments with various element combinations. Be sure to let them know the safety issues related to liquid nitrogen and strong magnet handling.

4.4 Let the train fly

4.4.1 Superconducting train: first example

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor. Strong magnets must be handled with care, avoid letting them "snap" together and avoid contact with credit, or other magnetic, cards.

Aim: to further investigate the properties of a superconductor

Apparatus: from the kit you will need
superconducting train – no.19;
two magnet stands – no.20 and 21;
small cube magnets – no.28;
(or magnetic field meter – no.13);
thick spacer – no.24;
liquid nitrogen.

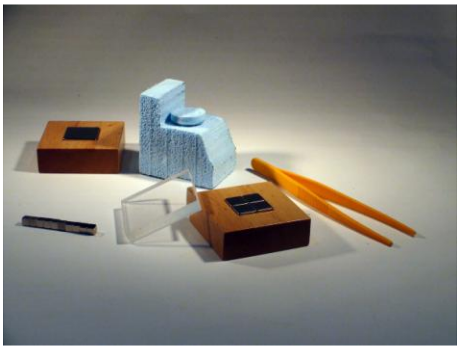


Fig. 4.4.1A Experimental set-up components.

Procedure:

Place a sheet of paper on the stands. Then, using the small magnets, determine the polarity of the stand magnets and draw it on the paper. Alternatively, use the magnetic field meter to determine the nature of magnet poles facing upward (north or south poles).

1. What do you notice about the polarity?

2. Which arrangement of magnets produces the higher field?

Place the spacer on the table, far from the stands and other magnets. Put the train on the spacer, pour liquid nitrogen into the train and wait for the boiling to stop.
Place the train on each stand in turn.

3. Which stand produces the better levitation?

4. Can you explain the reason?

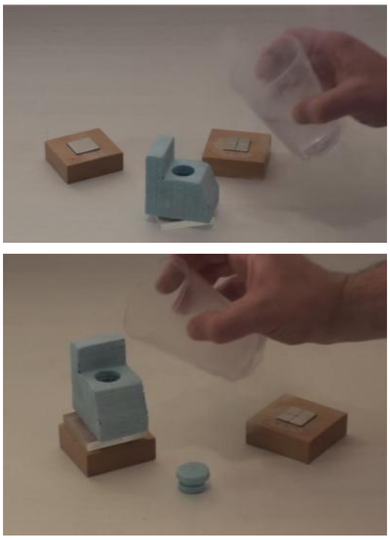


Fig. 4.4.1B Pouring liquid nitrogen.

Allow the pellet in the train to warm up the and superconductivity to be lost. Put the spacer on each stand and put the train on the spacer. Pour liquid nitrogen into the train, wait for the boiling to stop and take the spacer away.

5. Which stand produces the better levitation?

6. Can you explain the reason?

Explanation Sheet

1. The sheet of the paper helps to protect the stand's surface against damage by liquid nitrogen but the polarity should be observed as in fig. 4.4.1C.

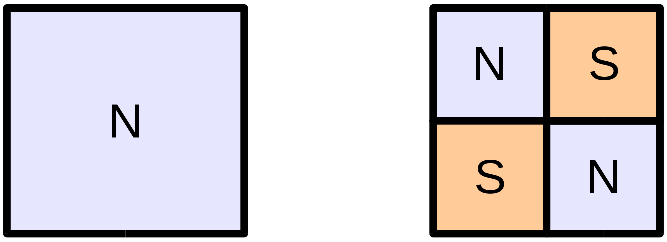


Fig. 4.4.1C Polarity of tracks. In some kits, north and south poles have been inverted.

2. When you are far enough from the stands (~4 mm), the alternating configuration produces the lowest magnetic field, since neighboring magnets will produce a magnetic field almost opposed in direction, which will diminish its amplitude. This can be checked by the magnetic field meter.

3. The train will not levitate over the single magnet stand, but will do it over the alternating configuration of magnets (with difficulty) - the levitation will be high but not very stable.

4. This is a zero-field cooled procedure. Since the pellet has strong pinning properties, the magnetic field cannot easily penetrate the pellet and is repelled from it.

5. Even though the magnetic field is higher in the single magnet configuration, the levitation is not as good: the train tends to slide sideways. However, the train levitates nicely over the alternating configuration stand.

6. This is a field cooled procedure. A superconductor with trapped magnetic flux will levitate because it opposes the change in magnetic field, and the alternate configuration produces the largest field changes (even if in absolute values the field is lower).

In the zero field cooled investigation, the magnetic field cannot penetrate the superconductor because of its strong pinning capacity, the vortices are prevented from moving freely and entering the sample. This is **not** the Meissner effect, but the consequences are similar in this configuration: the superconductor will behave as a perfect diamagnetic material. In the Meissner state, zero field cooled and field cooled procedures produce the same behavior - since if a magnetic flux is present as the pellet becomes superconductor, it is expelled; this is obviously not the case here.

Over the single magnet stand, the magnetic field is distributed around almost spherically. The magnetic field repulsion will cause the train to glide sideways and fall.

Over the alternating configuration stand the magnetic field is distributed in a more complicated manner, with a point at the center where the magnetic field is zero. This can be checked with the Hall probe sensor, or deduced from the symmetry of the setting. At the center, the magnetic field from all the magnets compensate to zero. There is, therefore, a valley of zero magnetic field at the center, surrounded by peaks of high value of magnetic field, over the magnets. It is possible to trap the superconducting pellet in this valley.

In the field cooled experiment, the magnetic field present in the pellet as it becomes superconducting is frozen in its bulk. However, the field around the single magnet configuration is slowly varying around it, so the pellet will not be strongly fixed in one place. On the other hand, over the alternating configuration stand, the magnetic field varies a lot, and setting the superconducting pellet in motion requires a lot of vortices to enter or exit from the pellet, which the strong pinning properties of the sample will fight against. Hence a better levitation is observed. It is important to understand that the quality of the levitation does not depend on the absolute value of the magnetic field, highest over the single magnet stand, but on the field variation.

4.4.2 Superconducting train: bad example

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor. Strong magnets must be handled with care, avoid letting them "stick" together and avoid contact with credit or other magnetic cards. Be careful when bringing magnets close to the tracks.

Aim: to further investigate the properties of a superconductor

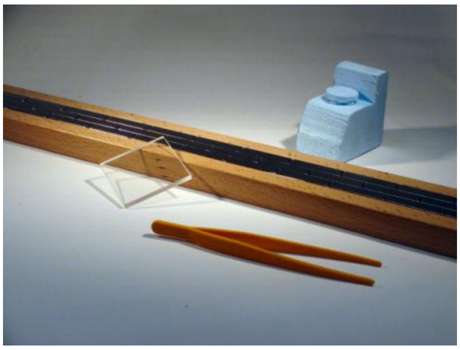


Fig. 4.4.2A Experimental set-up components.

Apparatus: from the kit you will need
superconducting train – no.19;
train tracks – no.10;
small cube magnets – no.28;
(or magnetic field meter – no.13);
medium spacer – no. 23.

Procedure:
Place a sheet of paper on the track. Then, using the small magnet, determine the polarity of the magnets that are part of the tracks and draw it on the paper. Alternatively, use the magnetic field meter to determine the nature of magnet poles facing upward (north or south poles).

1. What do you notice about the polarity?

Place the spacer on the table, far from the tracks and other magnets. Put the train on the spacer, pour liquid nitrogen into the train and wait for the boiling to stop.

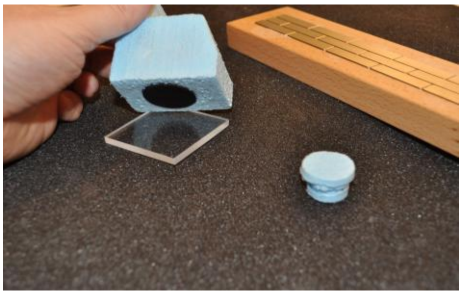


Fig. 4.4.2B Bottom of the train.

Place the train on the track.
Push, **gently,** the train perpendicular to the tracks.

2. What do you notice?

Push, **gently,** the train parallel to the tracks.

3. What do you notice?

Take the train off the track and try to put it back at 90° to the track.

4. What do you notice?

5. What do you think these observations mean for the safety of the train?

Explanation Sheet

1. The sheet of the paper helps to protect the track's surface against damage by liquid nitrogen but the polarity should be observed as in fig. 4.4.2C.

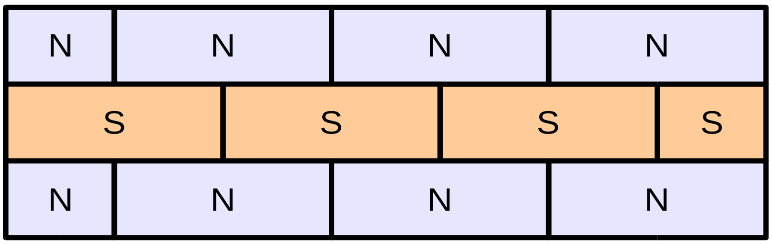


Fig. 4.4.2C Polarity of a track. In some kits, north and south poles have been inverted

2. The role of the spacer here is to protect the table. This procedure is called zero-field cooled, since no magnetic field is present in the bulk of the pellet during the cooling, when the pellet becomes superconducting. When the train is placed on the tracks it levitates high above the track. When it is pushed perpendicular to the track it swings and can be easily pushed off.

3. When the train is pushed parallel to the track it glides, without friction, but will fall off the tracks at the end.

4. It is easy to remove the train and replace it at 90° to the track. It is even possible to spin the train on the track.

5. As the train can easily be pushed sideways and spun its stability can be easily destroyed. The fact that the train falls from the end of the track, when traveling parallel to it, deteriorate the safety even more.

This investigation is very similar to the levitation investigation, but here a superconductor levitates above a magnet. The physics is the same as the levitation investigation: the pellet at the bottom of the train is a strong pinning pellet, allowing for a strong pinning of the magnetic field present in the bulk of the sample as it becomes superconducting. The "train" is a liquid nitrogen container that allows the sample to remain cool a longer time.

In the zero field cooled investigation, the magnetic field cannot penetrate the superconductor because of its strong pinning, the vortices are prevented from moving freely and entering the sample. This is **not** the Meissner effect, but the consequences are similar in this configuration: the superconductor will behave as a perfect diamagnetic material. In a Meissner state, zero field cooled and field cooled procedure produce the same behavior - since if a magnetic flux is present as the pellet becomes superconductor, it is expelled; this is obviously not the case here.

The train track presents two striking features. Along the tracks, the magnets present the same polarity: the magnetic field is thus the same along the length of the track; it is similar to a single 50 cm long magnet. On the contrary, perpendicular to the direction of the track, the magnets present an alternating configuration, with a strong variation of the magnetic field. Over the tracks, the magnetic field is distributed as two ridges with a valley of low value magnetic field at the middle of the tracks.

Since the field cannot penetrate inside the pellet, because of its strong pinning properties, the pellet is trapped in the valley of low value magnetic field, above the center of the tracks. The ridges around the valley are not very strong, so a weak push of the train, perpendicular to the tracks, will not make it fall, but a stronger push will do so.

Since the magnetic field hardly changes along the direction of the tracks, nothing will prevent the pellet from gliding in this direction if pushed. However, when arriving at the end of the tracks it will fall, since there are no magnets anymore.
Turning the pellet about its axis does not change anything as far as the magnetic field is concerned, only the weight of the train, which is not homogeneously distributed around the axis, will cause some preferential orientation.

4.4.3 Superconducting train: good example

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor. Strong magnets must be handled with care, avoid letting them "stick" together and avoid contact with credit or other magnetic cards. Be careful when bringing magnets close to the tracks.

Aim: to further investigate the properties of a superconductor

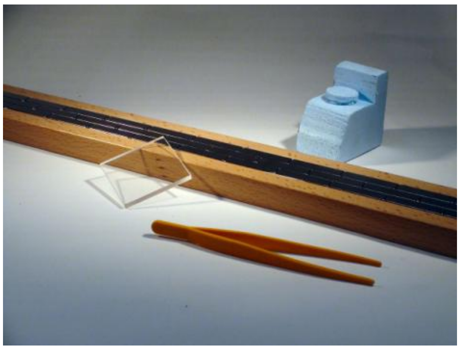


Fig. 4.4.3A Experimental set-up components.

Apparatus: from the kit you will need
superconducting train – no.19;
train track – no.10;
small cube magnets – no.28;
(or magnetic field meter – no.13);
medium spacer – no. 23.

Procedure:

Place a sheet of paper on the track. Then, using the small magnet, determine the polarity of the magnets that are part of the tracks and draw it on the paper. Alternatively, use the magnetic field meter to determine the nature of magnet poles facing upward (north or south poles). If you have done the bad train investigation (the experiment 4.4.2) this will be the same.

1. What do you notice about the polarity?

Place the spacer on the track, put the train on the spacer and slowly pour liquid nitrogen into the train and wait for the boiling to stop.
Remove the spacer.
Push, **gently,** the train perpendicular to the tracks.

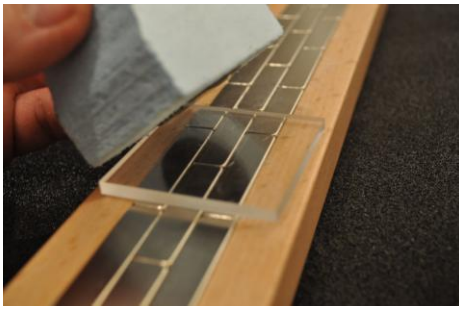


Fig. 4.4.3B Placing the train on the track.

2. What do you notice?

Push, **gently,** the train parallel to the tracks.

3. What do you notice?

Take the train off the track and try to put it back at 90° to the track.

4. What do you notice?

Whilst the train is levitating above the track, carefully lift the track and turn it upside down. Be careful not to pour liquid nitrogen onto you!

5. What do you think these observations mean for the safety of the train?

Explanation Sheet

1. The sheet of the paper helps to protect the track's surface against damage by liquid nitrogen but the polarity should be observed as in Fig. 4.4.3C:

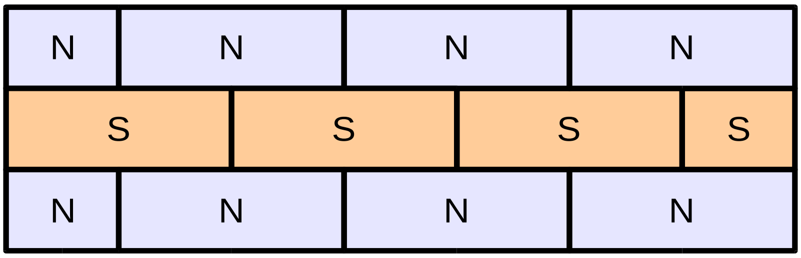


Fig. 4.4.3C Polarity of a track. In some kits, north and south poles have been inverted

2. This procedure is called field cooled, since a magnetic field is present in the bulk of the pellet during the cooling, when the pellet becomes superconducting. The magnetic flux is then trapped, and the train levitates when the spacer is taken away. Because the train is strongly pinned, it resists even a substantial push perpendicular to the track as this would require a large change in the field. Any spacer will do; the closer the train to the tracks, the stronger the pinning.

3. When the train is pushed parallel to the track it glides, without friction. However unlike the bad train example it "rebounds" at the ends and does not fall off the track.

4. It is difficult to take the train off the tracks; there is a force that opposes this action. When the train is replaced at 90° to the tracks it falls back either in its origin position or at 180° to it.

5. When the track is turned upside down the train "levitates" beneath the track, held in place by the strong pinning. If the superconductor is allowed to warm up above T_c then it will fall. As the train opposes rotation, does not fall from the end of the track and can cope with being upside down we have a much safer arrangement than in the bad train example (4.4.2).

This investigation is very similar to the levitation investigation, but here a superconductor levitates above a magnet. The physics is the same as the levitation investigation: the pellet at the bottom of the train is a strong pinning pellet, allowing for a strong pinning of the magnetic field present in the bulk of the sample as it becomes superconducting. The "train" is a liquid nitrogen container that allows the sample to remain cool a longer time.

In the field cooled experiment, the magnetic field present in the pellet as it becomes superconducting is frozen in its bulk. Perpendicular to the direction of the tracks, the magnetic field varies a lot. Since it is pinned in the superconductor, the train will resist any movement perpendicular to the tracks, as this would imply vortices entering or leaving the pellet. On the other hand, since the magnetic field hardly changes along the direction of the tracks, nothing will prevent the pellet from gliding in this direction if pushed. Arriving at the end of the tracks the pellet faces a big change in magnetic field, since there are no magnets anymore, but it will resist this change, and the train will "bounce" back.

Turning the pellet by 90° about its axis is not possible: the magnetic field of the two ridges is "frozen" in the superconducting pellet, and turning the pellet 90° represents a large magnetic field variation. However, a 180° turn is possible, since the magnetic field is the same in both ridges.

Turning the tracks upside down does not change the physics: the pellet still has a "frozen" magnetic image of the tracks in its bulk and any change, such as a free fall, will be resisted. The pinning strength of this pellet is enough to sustain its weight and allow a "reversed" levitation.

4.5. Hall effect

4.5.1 Measurement of the Hall coefficient for semiconductor samples

Student Worksheet

Aim: to quantitatively investigate the Hall effect for a semiconductor.

Apparatus: from the kit you will need

- the semiconducting Hall sample – no. 6.11;
- the USB interface with a cable to contact with PC – no.14 and 15;
- magnetic field meter – no. 12;
- the magnet holder – no. 5;
- foam cover of a magnet holder.

Moreover you will need:

- a PC with the acquisition system (CD provided with the kit) installed.

Fig. 4.5.1A Experimental set-up components.

Procedure:

Determine the relationship between injected current *I* and transverse Hall voltage V_H in a sample of thickness *S* (details see fig. 4.5.1B), inserted in a magnetic field *B*. Evaluate the Hall coefficient

$R_H = S\ V_H / (I\ B)$

The magnetic field should be orthogonal to the plane defined by the four connections. The cover from magnet holder is used to keep sample in the magnetic field – see fig. 4.5.1C

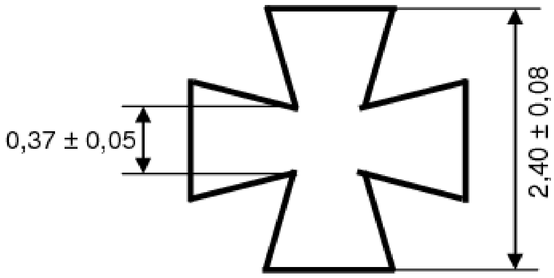
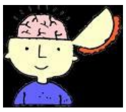


Fig. 4.5.1B Dimensions of the semiconducting probe, its thickness d = (150 ± 25) * 10^{-9}m.
The sample has a four point connections, two opposite used to inject the current and two others used to measure the Hall voltage.

1. How could you set up the apparatus?



Connect the sample to the USB interface and the interface to the computer. Start the acquisition program and setup the correct gain for the acquisition by selecting the relevant option ("Metal", "Semiconductor GeN", "Semiconductor GeP") in the drop-down menu situated in the upper part of the screen. Both semiconductor options work with the sample.

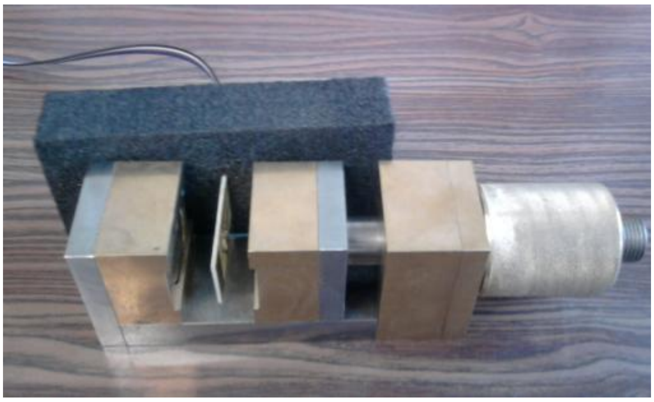


Fig. 4.5.1C Semiconducting sample inside the magnet holder – foam cover of a holder is used as sample possessor.

2. How could you investigate the effect of the injected current on the Hall voltage at constant magnetic field?

Choose a magnet configuration to create magnetic field with known B value measured with magnetic field meter in the middle of two magnets. Insert the sample in the same place you have made the measurement.
Initiate measurement procedure by pressing START, select the options in the current selection dialog window and confirm with OK. Data acquisition process begins.
The data acquired consist of couples of values V_H and I where the current I ranges between 3mA and I_{final}. Evaluate the Hall coefficient by determining the slope m of a straight line fitted to the data. The m value can be used to calculate the Hall coefficient $R_H = S\ m\ /\ B$ for the given material.

Note: Voltage channel of the USB system is saturated when the absolute value of voltage is around 23 mV therefore it is recommended to carry out measurements with given semiconducting sample at field B < 0.2 T and current 3 mA < I <10 mA (step 2 mA). In such circumstances you do not have to use magnet holder – one magnet no. 25 kept at distance of few centimeters from the Hall sample is sufficient to carry out the measurements.

3. How could you investigate magnetic field effect on the Hall voltage at constant current?

Insert the chosen sample in the space between the two magnets, in the middle of magnet holder. Set the acquisition mode to "Induction magnet control", initiate the measurement by pressing START, set constant current value and confirm with OK. Data acquisition process begins. Proceed to increase the distance between the two magnets (decrease magnetic field), by rotating the knob on the magnet holder for a given number of turns (three per step is optimal) and register the Hall voltage for each of the positions, without moving the sample.
Using a spreadsheet, graph the inverse of the measured V_{Hall} as a function of the distance between the two magnets. Take to the account the note above.

Further considerations on the Hall coefficient

The Hall coefficients R_H obtained can be correlated, for the different samples, to the features of the charge carriers in the materials.

The positive R_H value obtained for GeP – fig. 4.5.1D – shows that the charge carriers can't be negative particles, and the result is directly correlated to the charge carrier type (in this case holes).
For example, the value of the so called Hall mobility $\mu_H = R_H/\rho$ (where ρ is the resistivity of doped Ge) gives a value (for the shown data) of 0.2 $m^2\ V^{-1}\ s^{-1}$, which is very near to the drift mobility of the holes.

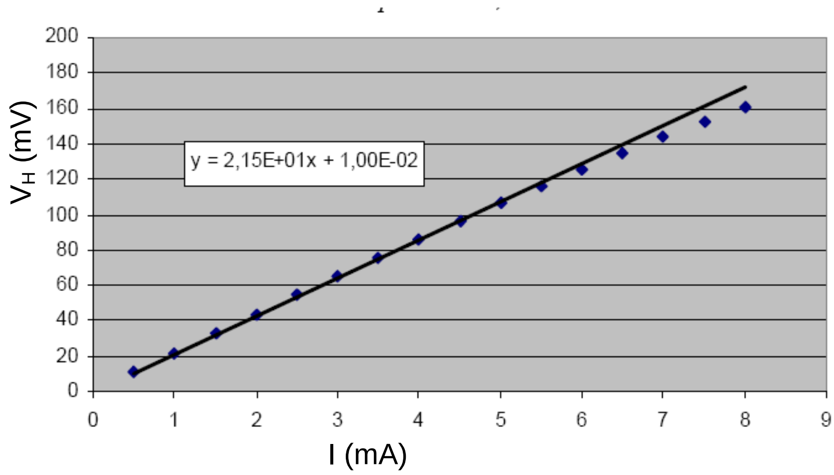


Fig. 4.5.1D An example of data obtained with GeP sample of thickness 6mm in a field B = 0,427 T.

4.4.4 Make your own train

Pedagogy

This is a recreational activity. Let the students test whatever idea they want to test.
It is best if this project takes several days, for the students to have time for devising and testing various strategies for making a train. Organize brainstorming sessions with the students, and let them take the decisions whenever possible.

Setup

Necessary equipment: Train tracks, strong pinning superconductor.

Hints

It is not necessary to follow the design of the MOSEM train, with the pellet tightly fitted to a hole at the bottom. The pellet could be fixed at the bottom of a plastic beaker, or a yogurt pot (something light and thin), and play a role of a beautiful train with some original decorations.

Observations

Ask the students to devise their own train. It should obey the following constraints:
- being liquid nitrogen tight;
- not being air-tight;
- the pellet should be reusable after the project is finished;
- the design should be original

Take a picture of their best trains and send it to the media.mosem.no web site corresponding pages, where they might get published.

The physics of the experiment

The physics here is that of the experiments of superconducting train 4.4. The aim is to provide a group of students with the project which will be able to give free rein to their creativity.

The only important constraint is that the train should not be air-tight, and this is really important. Liquid nitrogen in a closed volume is dangerous, since the pressure will go up rapidly and eventually the train would explode.

4.4.5 Pyrolytic graphite on tracks

Setup

Necessary equipment: two magnet stands – no.20 and 21, train tracks, pyrolytic graphite thin slab (wafer) ~ 10x10 mm^2.

Prepare the pyrolytic graphite slab beforehand, specially if the students are young. See the teacher guide for details on how to proceed.

Do this activity after having performed the experiment 4.4.1.

See also video at: http://www.youtube.com/user/MOSEMwp7#p/u/4/ozmk_Lnw1J4

Observations

Try to make the pyrolytic graphite slab levitate over both stands. Try to make it levitate over the train tracks.

Minds-on questions

Magnet over diamagnet, or diamagnet over magnet, is this the same?

Why does the graphite levitate over the inverted configuration stand?

What is the difference between a zero field cooled strong pinning superconductor and the Meissner state?

The physics of the experiment

Trying to make the pyrolytic slab levitate over the single configuration stand is exactly the same experiment that in the additional activity "Meissner versus diamagnetic levitation". The graphite does not levitate. On the other hand, it levitates over the inverted configuration stand. This is because the configuration, with no magnetic field at the centre, creates a valley of magnetic field, which can be seen with the gaussmeter. This configuration prevents the slab from gliding aside.

On the tracks, the graphite slab will behave like the bad superconducting train (activity 4.4.2). The levitation is not very stable, the slab falls if the tracks are turned upside down, and it also falls at the end of the tracks. The physics here is actually the same, since a zero field cooled strong pinning pellet behaves like a perfect diamagnet even at fields a bit larger than B_{c1}, since the pinning prevents the magnetic field from entering the pellet, up to a limit.

Sometimes the graphite slab can be stuck in the place where the magnets join. This is because at this junction the magnetic field is slightly perturbed and a small valley may appear.

4.6 Gadolinium Experiment

4.6.1: Investigating gadolinium with a multimeter

Student Worksheet

Safety Issues:
Liquid nitrogen can be dangerous due to both cryogenic burns and asphyxiation. The first of these can be minimized 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 please ask your local safety advisor.

Aim: to investigate the magnetic properties of gadolinium with a self-inductance meter.

Apparatus: from the kit you will need: piece of gadolinium – no.6.4; coil – no.18; self-inductance meter – no.12; temperature sensor – no.11; You will also need a hair dryer; liquid nitrogen or a refrigerator.

Fig. 4.6.1A Experimental set-up components.

Procedure:
Connect the coil into the self-inductance meter.

1. What do you observe on the multimeter screen when the piece of gadolinium is outside or inside the coil?

Place the piece of gadolinium in a refrigerator or cooled it down otherwise to temperature around 6°C. When it is done attach the temperature sensor and put the sample into the coil. Connect the coil to the self-inductance meter.

2. What do you observe on the multimeter screen when the piece of gadolinium is outside or inside the coil now?

Place the piece of gadolinium in the coil and let it to warm up above the temperature of 20°C (you may use hair dryer to speed up the process).

3. What do you observe when the temperature is rising?

Fig. 4.6.1B Measurements procedure.

Cool the piece of gadolinium once more and repeat the procedure described above but try to register (write down) the values of the temperature (T) and corresponding self-inductance (L) when gadolinium is warming up above the temperature of 20°C (you may use hair dryer to speed up the process).

4. Can you explain your observations?

Measure self-inductance of the coil without a piece of gadolinium inside (L_0). Basing on the obtained results try to draw a figure that represents the dependence of $(L/L_0 - 1)^{-1}$ on temperature T for the above activity. Compare your results with those presented in T. Lewowski, K. Wozniak, *Measurement of Curie temperature for gadolinium: a laboratory experiment for students*, Eur. J. Phys. **18** (1997) 453–455

Explanation Sheet

1. Above the characteristic temperature, called the Curie temperature, ferromagnetic substances become paramagnetic.

2. The magnetization vector *M* changes with temperature according to the Curie–Weiss law
$X = \mu - 1 = C'/(T-\theta)$ where X and μ are, the magnetic susceptibility and magnetic permeability of the substance, respectively, C' is a constant characteristic for a given substance and θ is Curie temperature.

3. The self-inductance of a coil with a gadolinium core may be calculated from equation $L = \mu \cdot L_0$, where L_0 is the self-inductance of an empty coil (air), therefore $\mu = L/L_0$

4. Taking into account a geometrical factor γ of the fraction of magnetic lines closed in an investigated core, one may write that $\mu = \gamma L/L_0$ and then derive: $X^{-1} = (\gamma L/L_0 - 1)^{-1} = (T-\theta)/C'$

Thus $(\gamma L/L_0 - 1)^{-1}$ is an linear function of temperature T (above $T = \theta$), characterized by the slope $1/C'$ and the intercept $-\theta/C'$. The function is equal to zero if $T = \theta$. Thus, the intersection of the straight line with the horizontal (temperature) axis directly determines the value of the Curie temperature.

Additional Experiment

Other shapes of the gadolinium piece or a different type of coil may be investigated for the comparison of the results.

4.6.2 Investigating a superconductor with a multimeter

Setup

Necessary equipment: high pinning superconductor, coil – no.18, multimeter – self-inductance meter – no.12, liquid nitrogen.
Connect the coil into the self-inductance meter. Place the superconductor in the coil and read the multimeter indication. Repeat observation with a cooled superconductor.

Observations

Watch how the multimeter readings change in different situation and with time (when the superconductor is warming up in the air).

Minds-on questions

What do you observe on the multimeter screen when the superconductor is outside or inside the coil?
What do you observe on the multimeter screen when the cooled superconductor is outside or inside the coil?
What do you observe when the temperature is rising?

Evaluation

The MOSEM proposal sets out that the final results would be evaluated via a series of trials in schools in the partner countries, and that teachers from the target group will be involved in these trials. The teachers will report on their use of the materials, their curriculum relevance (within their country), the impact on students learning and motivation and any impact on equality and discrimination issues.

It is considered vital that some measure of impact on motivation, curriculum relevance and gender be addressed. The following items were not evaluated:

- The project collaboration
- Computer applications
- Support for learning English
- Students of different aptitudes
- Inter-country comparisons

The latter two of these have too many cultural components to generate meaningful data within a project of this scale. The third of these was not in the proposal.

Tools

The project used three tools to collect data from teacher seminars and classroom trials for the evaluation report, two questionnaires and one interview form:

- Questionnaire for teacher seminar participants
- Questionnaire for students after classroom trials
- Interview form for teachers after classroom trials

These forms are reprinted below, for reference when considering the evaluation report.

Student questionnaire after classroom trials

We would like your help to improve the MOSEM teaching approaches and materials for future students.

For each of the questions 3-20 please circle one of the numbers 1 to 5, indicating the how much you agree with the statement. The meaning of the numbers is as follows:
.

5 - Strongly agree	4 - Agree	3 - Neutral	2 - Disagree	1 - Strongly disagree

ABOUT YOU							
1. Male/Female:							
2. Age:							
3. I find science interesting	Strongly agree	5	4	3	2	1	Strongly disagree
4. I find physics interesting	Strongly agree	5	4	3	2	1	Strongly disagree
5. I am interested in the	Strongly	5	4	3	2	1	Strongly

medical and communication applications of technologies	agree						disagree
6. I am interested in the military applications of technologies	Strongly agree	5	4	3	2	1	Strongly disagree
ABOUT THE EXPERIMENTS							
7. The experiments were interesting	Strongly agree	5	4	3	2	1	Strongly disagree
8. The experiments were hard to do	Strongly agree	5	4	3	2	1	Strongly disagree
9. The experiments were useful	Strongly agree	5	4	3	2	1	Strongly disagree
10. There were no difficulties in carrying out the experiments	Strongly agree	5	4	3	2	1	Strongly disagree
11. I did need a lot of help from the teacher to understand what was going on in the experiments.	Strongly agree	5	4	3	2	1	Strongly disagree
12. I took an active role during the experiments	Strongly agree	5	4	3	2	1	Strongly disagree
13. The students worked together on the experiments and discussed them	Strongly agree	5	4	3	2	1	Strongly disagree
GENERAL							
14. Which parts of the MOSEM course did you particularly like? Please give reasons for your answer.							
15. Do you think that you have learned through the MOSEM lessons? Please give reasons for your answer.							
16. List two things that you thought were particularly good about the MOSEM lessons: A B							
17. List two things that you thought were not good about the MOSEM lessons: A B							

18. Would you recommend the MOSEM lessons for the other pupils? Please give reasons for your answer.
19. What changes or improvements would you suggest for the MOSEM lessons?
20. Are there any other comments that you wish to make about the MOSEM lessons?

Interview form for teachers after classroom trials

Which experiments were used?[13]

Context
Question: Describe the school context in which you used the experiment.

Prompt questions to be used as necessary:

- Was the experiment suitable for your school context? Please explain.
- Was the experiment presented by the teacher to the whole class, carried out in small groups, or carried out individually by the students? Which method do you think would be most appropriate?
- Explain the role of the experiment in terms of the learning path. Did you use the experiment for a specific learning goal, or to address a range of learning goals?
- What other experiments might be appropriate to use alongside this experiment? Please explain.

Experiment
Question: Describe how the experiment was carried out.

Prompt questions to be used as necessary:

- Was the experiment easy to carry out?
- Did the experiment work as you expected?
- Were there any difficulties in carrying out the experiment?
- Was the multimedia support easy to use?
- Do you have any suggestions as to how the experiment could be improved? Please explain.

Usefulness
Question: What had the students learned after their analysis of the experiment?

[13] Adjust questions to plural if more than one experiment was carried out

Prompt questions to be used as necessary:

- Which (phenomenological and/or conceptual) aspects were most frequent in the students' analysis of the experiment?
- Did the experiment support a transition from a purely descriptive level to an interpretative level? How often and in what ways? How complete is the description? Which interpretative aspects emerge?
- What is your opinion on the usefulness of the experiment, taking into account the students' responses?

Effectiveness

Question: Make a list of the learning goals for the Classroom Trial and indicate the degree of achievement (or not) for each.

Prompt questions to be used as necessary:

- In discussing the experiment, did students introduce questions, did students introduce interpretative elements?
- Did students take an active role during the experiment? Please explain how.
- To what extent was it necessary to guide students in understanding the phenomenon?
- Did the experiment encourage group work, and collaboration and discussion between students?

Questionnaire for teacher seminar participants

We would like your help to improve the Teacher Seminar for future teachers.

For each of questions 3-18 please circle one of the numbers 1 to 5 indicating the how much you agree with the statement. Here the numbers have the following meanings:

.

5 - Strongly agree	4 - Agree	3 - Neutral	2 - Disagree	1 - Strongly disagree

For questions 19-35 indicate how useful you found aspects of the materials and seminar here the numbers have the following meanings:

5 –Very useful	4 – Quite useful	3 - Neutral	2 – Not very useful	1 – Not at all useful

ABOUT YOU
1. For how long have you taught physics? If you have previously taught other subjects, then please also say how long you have been a teacher:
2. Do you have a first degree in physics? If not, then please state the subject of your first degree)

To what extent you agree with the following statements?							
3. I found physics interesting when I was at school	Strongly agree	5	4	3	2	1	Strongly disagree
4. The subject of superconductivity is interesting	Strongly agree	5	4	3	2	1	Strongly disagree
5. I find using experiments with students interesting	Strongly agree	5	4	3	2	1	Strongly disagree
6. Medical and communication applications of technologies are more likely to appeal to female students than other applications of technologies	Strongly agree	5	4	3	2	1	Strongly disagree

ABOUT THE TEACHER SEMINAR							
7. The seminar was stimulating	Strongly agree	5	4	3	2	1	Strongly disagree
8. The seminar was not suitable for my level of skills	Strongly agree	5	4	3	2	1	Strongly disagree
9. The seminar improved my subject knowledge	Strongly agree	5	4	3	2	1	Strongly disagree
10. The seminar presented materials and approaches suitable for the students that I teach	Strongly agree	5	4	3	2	1	Strongly disagree
11. I am likely to use the materials from the seminar in my school	Strongly agree	5	4	3	2	1	Strongly disagree
12. The seminar improved my pedagogical knowledge	Strongly agree	5	4	3	2	1	Strongly disagree
13. The seminar will help me to develop teaching methods based on active learning	Strongly agree	5	4	3	2	1	Strongly disagree
14. The seminar helped me to understand better how students learn	Strongly agree	5	4	3	2	1	Strongly disagree
15. The seminar provided materials that will enable me to continue my own learning	Strongly agree	5	4	3	2	1	Strongly disagree
16. I am likely to take new professional development courses in the future	Strongly agree	5	4	3	2	1	Strongly disagree
17. The MOSEM materials and approach to teaching are likely to promote equality between men and women	Strongly agree	5	4	3	2	1	Strongly disagree

ABOUT THE MOSEM MATERIALS
To what extent do you consider the following MOSEM materials likely to be useful for your teaching?

18. Subject information	Very useful	5	4	3	2	1	Not at all useful
19. Experiments generally	Very useful	5	4	3	2	1	Not at all useful
20. Series of Low-Tech experiments	Very useful	5	4	3	2	1	Not at all useful
21. Series of High-Tech experiments	Very useful	5	4	3	2	1	Not at all useful

ABOUT THE ORGANISATION OF THE TEACHER SEMINAR							
How useful did you find each of the following aspects of the Teacher Seminar?							
22. Presentations	Very useful	5	4	3	2	1	Not at all useful
23. Workshop discussions	Very useful	5	4	3	2	1	Not at all useful
24. Plenary discussions	Very useful	5	4	3	2	1	Not at all useful
25. Practical sessions	Very useful	5	4	3	2	1	Not at all useful

26. Which parts of the seminar were most useful to you in developing your knowledge, skills and confidence?
27. Were any parts of the seminar not useful to you? Why?
28. What should be changed/improved in the Teacher Seminar?

CONCLUSION
29. Are there any other comments that you wish to make about the Teacher Seminar or the MOSEM materials?

Thank you for your help.

Evaluation report

Evaluation of the MOSEM project was conducted using questionnaire and interview data from both teachers and school students. The data capture instruments can be found in the appendix of this report.

School students

The feedback collected from school students can be summarised as follows:

Gender split: 35% female, 65% male
Age range: 15 – 18 years
Average age: 17.25 years

In summarising questions 3 through to 13, since ordinal data are being used, modal rather than mean values will be reported:

Question	3	4	5	6	7	8	9	10	11	12	13
Modal value	4	4	4	4	4	2	4	5	2	5	5

The responses to questions 3 to 6 show agrement with the statements regarding interest in science, interest in physics and in both medical and millitary applications of technology. However differences between male and female responses can be seen:

Question	3	4	5	6
Male mode	4	4	4	4
Female mode	4	3	3	3

Whilst this may appear to show a difference in interest between male and female students how a Chi-square analysis is run on these data a value of 0.945 is returned which is not significant at the 0.1 level [critical value 6.25 with 3 degrees of freedom].

Questions 7 through to 13 are concerned with students' response to the experiments. Questions 8 and 11 can be seen to show disagreement with the statements but these two are written in the negative:

Q8: The experiments were hard to do.
Q11: I did need a lot of help from the teacher to understand what was going on in the experiments.

Hence in terms of the project data collected on the experiments shows good or very good student response.

In terms of gender difference in response to the experiments we have:

Question	7	8	9	10	11	12	13
Male mode	4	2	4	5	3	5	5
Female mode	4	2	4	5	1	5	4

Whilst this shows a difference, especially on question 11, with female students needing less help from the teacher, again the significance is low. The Chi square value returned being 0.957 [critical value 10.65 with 6 degrees of freedom at the 0.1 level].

Questions 14 through to 20 allowed for a narrative response which the project can use to both develop the materials and triangulate finds from the Likert style questionnaire data.

Whilst the responses showed some variation, especially given collection across a number of educational and cultural contexts, a number of common responses can be extracted from the data.

Q14 Which parts of the MOSEM course did you particularly like?

Making the electric motor
Viewing field lines

Q15 Do you think you have learned through th MOSEM lessons?

Yes, better understanding of Fleming's right hand rule
Yes, seeing things in action

Q16 List two things that you thought were particularly good about the MOSEM lessons.

Having fun
Seeing how science works
Experiments easy to set up/carry out

Q17 List two things you thought were not good about MOSEM lessons.

Not enough time to explore all possibilities

Q18 Would recommend the MOSEM lessons for the other pupils?

Yes; its's fun, it lets you see science in action.

" It is interesting and at the same time challenging" – comment from a Norwegian student.

This latter comment goes to the heart of the Minds-on approach – interest and challenge.

Q19 What changes or improvements would you suggest for the MOSEM lessons?

More time
More [and bigger] experiments

Q20 Are there any other comments that you wish to make about the MOSEM lessons?

No universal comments could be extracted from these responses but all included some statement of *thanks* and *interest.*

Teacher seminar participants

As with the student questionnaire, due to the ordinal nature of the data, modal rather than mean values will be returned. The analysis here will be seperated into;

a. About the participants;
b. About the seminar;
c. About the materials;
d. About the organisation.

Participants
The teachers attending a seminar range in years of teaching experience from 1 year to 38 years [one Polish teacher], the mean number of years teaching being 18.

The cohort was equally split between those who have a first degree, or higher qualification, in physics and those who do not [49% to 51%].

Questions 3 through to 6, which replicate those on the student questionnaire address *interest* the modal values from the data are as follows:

Question	3	4	5	6
Modal value	5	5	5	4

When separated by having, or not having, a physics degree this becomes:

Question	3	4	5	6
Physics graduate	5	5	5	4
Non-physics graduate	5	5	4	4

These data clearly show a high level of interest from teachers in science, physics and applications. This was to be expected from teachers who attend Professional Development courses but within the project it is good to have these expectations confirmed.

Teacher Seminar
Questions 7 through to 17 address the Teacher Seminar, and once again modal values show:

Q	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
Mode	5	1	4	5	5	4	5	4	5	5	5

Question 8 shows a strong disagreement but when the nature of the question is explored, *the seminar was not suitable for my level of skill,* we see that this is a strongly positive statement in favour of the project.

Furthermore, again we see a clear agreement between teachers with or without a physics background:

Q	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
Physics	5	2	4	5	5	4	5	4	5	4	5
Not physics	5	1	4	5	5	4	5	4	4	5	5

Materials
Questions 18 through to 21 address the materials, and the modal values for the whole cohort and physics/non-physics graduates is as follows:

Question	18	19	20	21
Whole cohort	5	5	5	5
Physics graduate	5	5	5	5
Non-physics	5	5	4	5

Organisation
Questions 22 through to 25 address the organisation of the teacher seminar.

Question	22	23	24	25
Whole cohort	4	4	4	5
Physics graduate	4	4	4	5
Non-physics	5	4	5	5

Summary

In light of these data the group can be confident that *both the students and the teachers are positive* about the materials and the nature of the Minds-on presentation.

It is also encouraging for the project to report that response from *male and female* students and *teachers with and without a physics degree* is equally positive.

Valorisation

Activities

Reference groups

Partners nominated peers, politicians, teachers and other relevant contacts as reference group members. These reference groups are to be contacted electronically with information about the project results.

Conferences and meetings

The project was presented at a number of occasions from smaller meetings to larger conferences (e.g. MPTL, GIREP), reaching local, national and international audiences.

Valorisation partners

Some of the partners were chosen specifically for their ability to disseminate the project results. Among their efforts can be mentioned the publishing of articles relating to the project activities in teacher magazines, listing the project among efforts to promote and improve physics teaching in presentations for politicians, and Science Centres implementing learning activities from the project.

Materials

A number of materials were developed specifically for valorisation, and several of the project deliverables are also suitable for drawing attention in order to disseminate project results.

Presentations and posters

The project was presented at a number of conferences, and there are several presentation files and also posters available from these occasions.

Fact sheets

The standard fact sheet template from the National Agency was completed and translated by the partners to nearly all languages in the project.

Project homepage

Information about the MOSEM project was added to the overall website for all projects in the SUPERCOMET family (supercomet.eu). The resources mentioned above (presentations, posters, fact sheets) can be downloaded from the project homepage.

Online discussion forum

Teachers participating in the testing and evaluation of MOSEM deliverables were introduced to the online discussion forum established by the project (forum.mosem.eu). The forum will be used also after the project period.

Online videos and animations

The project's YouTube channel (youtube.mosem.eu) and online learning modules (online.supercomet.eu) get significant attention and provide ongoing valorisation and publicity.

Resources

Q&A about Superconductivity

We have provided answers to a few questions about Superconductivity and Electromagnetism. More information can be found in the resources listed under References.

What is the temperature of liquid nitrogen?
Liquid nitrogen is boiling at room temperature and ambient pressure. Its boiling temperature is 77 K.

Why is liquid nitrogen boiling and still be cold?
Because a liquid can not be at a temperature above its boiling temperature. A bucket of water, put in 300^{o}C oven will warm up till 100^{o}C and then the temperature will stop and the water will begin to boil. The water will appear to be cold to someone used to the hot temperature of the oven.

Why is liquid nitrogen fuming?
Nitrogen gas is transparent (it constitutes 80% of the atmosphere). The white fumes are due to the condensation of the humidity of the atmosphere in the cold air above the liquid nitrogen.

Is liquid nitrogen dangerous?
If handle with care, liquid nitrogen is not dangerous. If a small drop of liquid nitrogen falls on your arm, it will evaporates before doing any damage. However it is possible to get burnt if touching an object that has been cooled down to liquid nitrogen temperature. Always use tweezers to manipulate cold objects.

Can I play with liquid nitrogen?
It is best to treat liquid nitrogen with respect. With the presence of a teacher, there are many experiments that are interesting to carry on with liquid nitrogen.

Why the liquid nitrogen drops behave so strangely?
The bottom of the drops evaporates due to the warmness of the table. It creates a gas cushion that allows the drop to move frictionless. Star-shaped drop can be observed, due to an mechanical oscillation of the drop.

Is there really liquid helium in an hospital MRI?
Yes, all around the superconducting magnet. When a patient is put in the machine, he is surrounded by liquid helium, at 4 kelvins. Fortunately the thermal protection is quite good.

Is superconductivity a rare property?
A lot of metals are superconductors, and also a lot alloys, so it is not really a rare property. However, superconductivity only appears at low temperature.

Do the cuprate superconductors exist in nature?
No, even if similar crystallographic structures do exist. They are made in laboratories.

Why does a disk magnet rotate when levitating?
A disk magnet, with the poles on both flat sides of the disk, creates a magnetic field around it that has the axis of the disk as an axe of symmetry. When the magnet rotates around this axis, the magnetic field does not change, so there is nothing to brake the rotation.

Why does a square magnet rotate when levitating?
A square magnet produces a magnetic field that is not symmetric around its central axis. The difference is very small (a square is almost a circle!) so that there is little to brake the rotation, however one can feel some bumps in the rotation.

How does maglev work?
There are various magnetic levitation (maglev) devices with different principles. One maglev uses a superconducting coil to produce a very large magnetic field, a sort of giant magnet. The levitation of the train is then assured by eddy currents produced in coils buried in the tracks by the movement of this “magnet”. See the bibliographic section for further reading. Note that the HTK experiment 4.4.3 does not represent the principle of the Maglev; here it is the pinning of the vortex that allows the train to levitate.

What kind of magnets are used?
The magnets that are used here are Neodymium-Iron-Bore alloy. They are the strongest permanent magnets available today. Electromagnets using copper or even superconducting wires can generate much stronger magnetic fields.

References

Books

Introduction to Quantum Physics

In Search of Schrödinger's Cat: Quantum Physics and Reality, by John Gribbin, Bantam Books.
Good introduction to quantum mechanics, no equations, only the notions are introduced and clearly explained.

Quantum Physics: A First Encounter Interference, Entanglement, and Reality, by Valerio Scarani, Oxford University Press.
Very clear explanation of entanglement in quantum mechanics. No equations, the emphasis is on the understanding.

Introduction to superconductivity

The rise of the superconductors, by Peter John Ford and G. A. Saunders, Taylor & Francis Ltd.
An introduction to superconductivity, explains clearly its properties, a bit its history, and discuss its possible applications.

Superconductivity: the next revolution? by Gianfranco Vidali, Cambridge University Press
An introduction to superconductivity, explains clearly its properties, a bit its history, and discuss its possible applications.

History of superconductivity

The Cold Wars: A History of Superconductivity, by Jean Matricon and G. Waysand, Rutgers University Press
A history of the quest for understanding superconductivity, all through the 20th century. A very nice introduction to superconductivity centred on its history (the physics is also present, but not that much).

The Breakthrough: The Race for the Superconductor by Robert M. Hazen, Simon & Schuster
The recollection, almost day by day, of the frantic months following the discovery of the high temperature superconductors.

University textbooks on superconductivity

Superconductivity: Fundamentals and Applications, by Werner Bückel and Reinhold Kleiner, Wiley-VCH; 2 edition
Modern presentation of superconductivity, with link to recent research results and a discussion of the applications.

Superconductivity: Physics and Applications, by Kristian Fossheim and Asle Sudbø, Wiley
Modern presentation of superconductivity, with link to recent research results and a discussion of the applications.

Introduction to Superconductivity, by Michael Tinkham, Dover Publications Inc.
The reference classical textbook.

Superconductivity, Superfluids, and Condensates, by James F. Annett, Oxford University Press
An original approach of superconductivity, through the collective quantum modes (Bose-Einstein condensation).

Articles

Electromagnetism

Magnetic Flux Diffusion and Expulsion with Thin Conducting Sheets by Yao Liu and John W. Belcher

W. M. Saslow, *Maxwell's Theory of Eddy Currents in Thin Conducting Sheet*, and Applications to Electromagnetic Shielding and MAGLEV," Am. J. Phys. 60 (Cool, 693-711 (1992).

W. M. Saslow, *How a Superconductor Supports a Magnet, How Magnetically 'Soft' Iron Attracts a Magnet, and Eddy Current for the Uninitiated*, Am. J. Phys. , 59(1), 16-25 (1991).

Quantum physics

Demonstration of single-electron buildup of an interference pattern, by A. Tonomura et al., Am. J. Phys. 57, 117 (1989)
The famous single electron interference experiment by the Hitachi group.

Quantum interference experiments with large molecules, by O. Nairz, M. Arndt, and A. Zeilinger, Am. J. Phys. 71, 319 (2003)
Interference pattern of fullerenes. Quantum physics also applies to large molecules.

Resource letter SH-1: superfluid helium, by R. B. Hallock, Am. J. Phys. 50, 202 (1982)
List of references dealing with superfluidity of helium.

Superconductivity

Kamerlingh Onnes and the discovery of superconductivity, by P. H. E. Meijer, Am. J. Phys. 62, 1105 (1994)
A recollection of Onnes' historical discovery.

High-Temperature Cuprate superconductors get to work, by A. P. Malozemoff, J. Mannhart, and D. Scalapino, Physics Today 58, 41 (2005)
http://www.physik.uni-augsburg.de/exp6/news/Physics%20Today%20HTS%20Applications.pdf
Applications and use of the high Tc superconductors.

The formation of Cooper pairs and the nature of superconducting currents, by V. F. Weisskopf, CERN (1970)
http://cdsweb.cern.ch/record/880131/?ln=sk

An explanation of superconductivity, does not get too much into the quantum explanation and prefers to insist on the understanding, but with the help of many equations. Rather an advance reading.

Resource Letter Scy-3: superconductivity, by N. P. Butch, M. C. de Andrade, and M. B. Maple, Am. J. Phys. 76, 106 (2002)
An introduction to modern developments in superconductivity research, with many bibliographic references. Not an introduction to superconductivity itself, rather an advance reading.

Magnetic braking revisited: activities for the undergraduate laboratory
G. Ireson, J. Twidle - European journal of physics, 2008
A description of the magnet falling in a tube, one of the Low-Tech Kit activity

Measuring the transition temperature of a superconductor in a pre-university laboratory, G. Ireson - Physics education, 2006
How to measure the superconducting transition in a superconductor (related to the High-Tech Kit 4.1 activity).

Levitation and vortex pinning

A floating magnet, by V. Arkadiev, Nature 160, 330 (1947)
The first levitation of a magnet, over a type I superconductor, at very low temperature.

Magnetic levitation, by T. D. Rossing and J. R. Hull, the physics teacher 29, 552 (1991)
A description of the various magnetic levitations, with a comprehensive description of the Maglev principles.

Rigid levitation and suspension of high-temperature superconductors by magnets, by E. H. Brandt, Am. J. Phys. 58, 43 (1989)
Complete description of the superconducting levitation.

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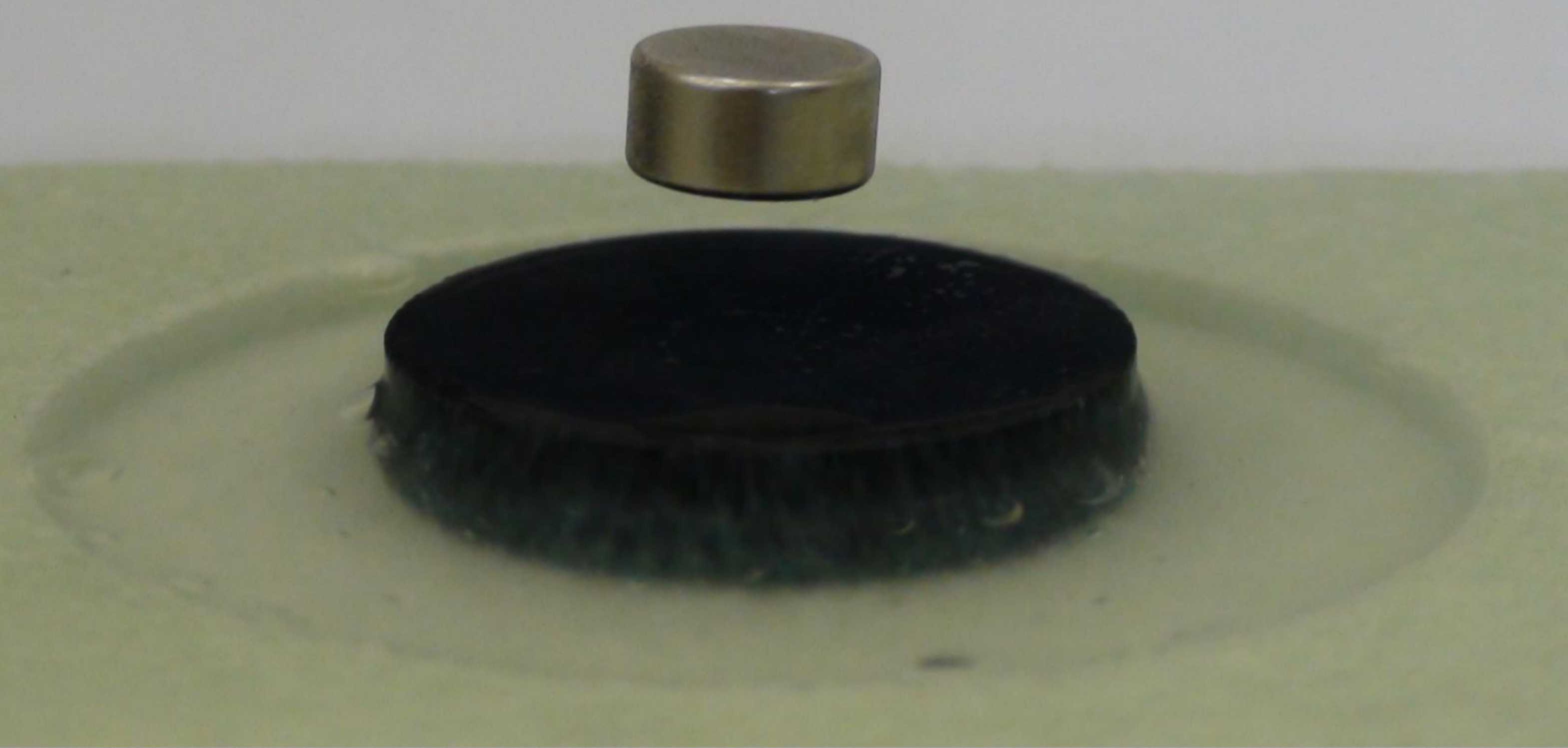
Simulates vortex pinning using Maxwell equations and a modified Ohm’s law

Levitating magnets attract students' minds



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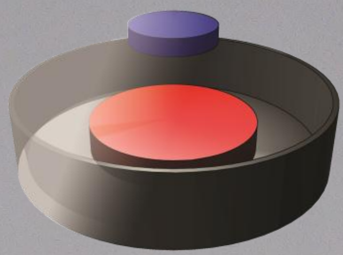

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