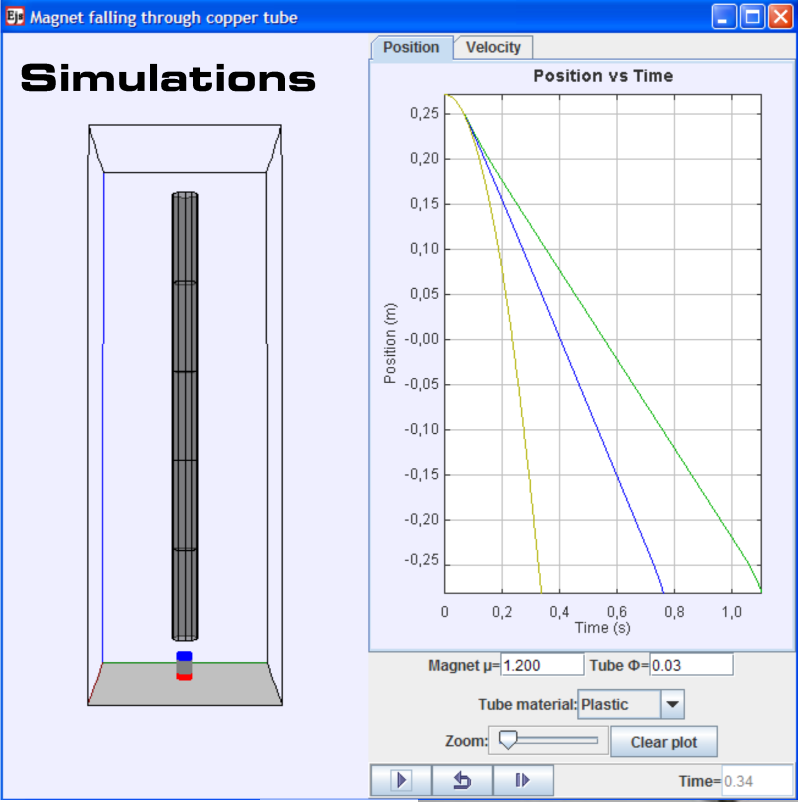
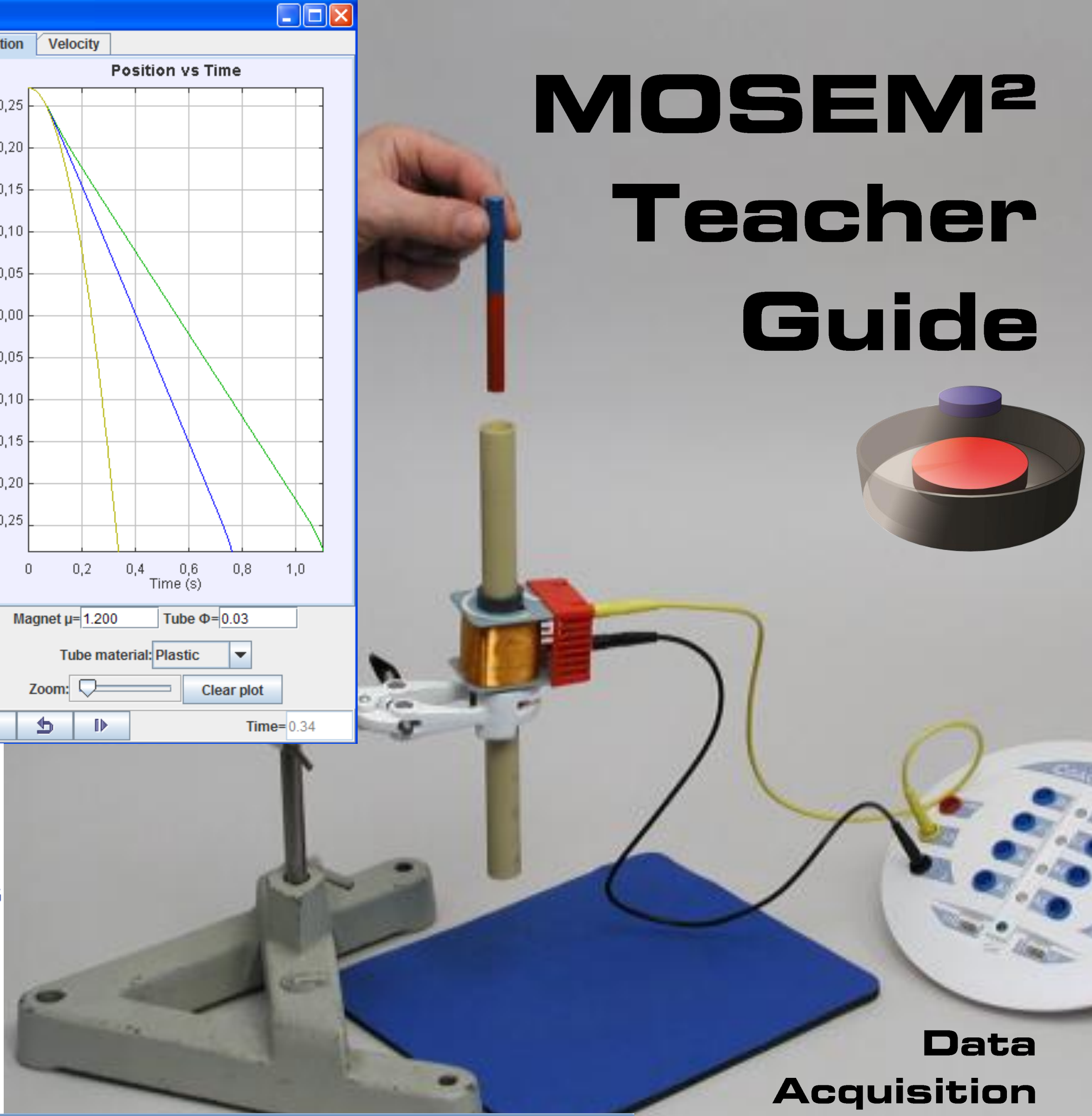
MOSEM² Teacher Guide

Simulations



Data Acquisition



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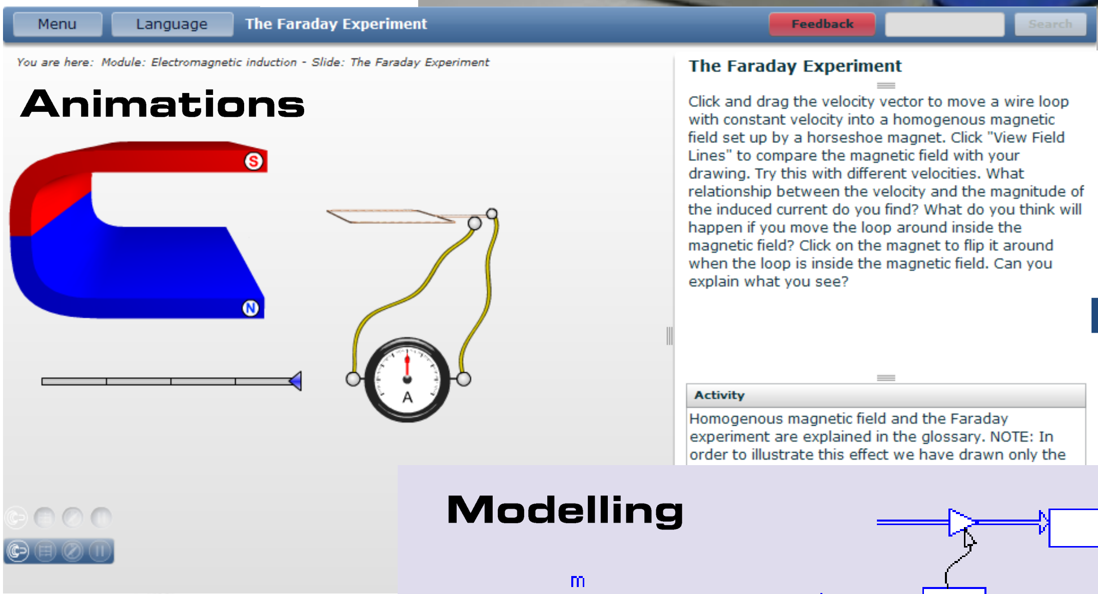
Animations



SRD Simplicatus Research and Development

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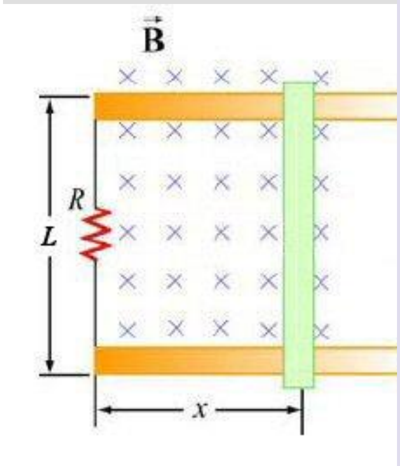

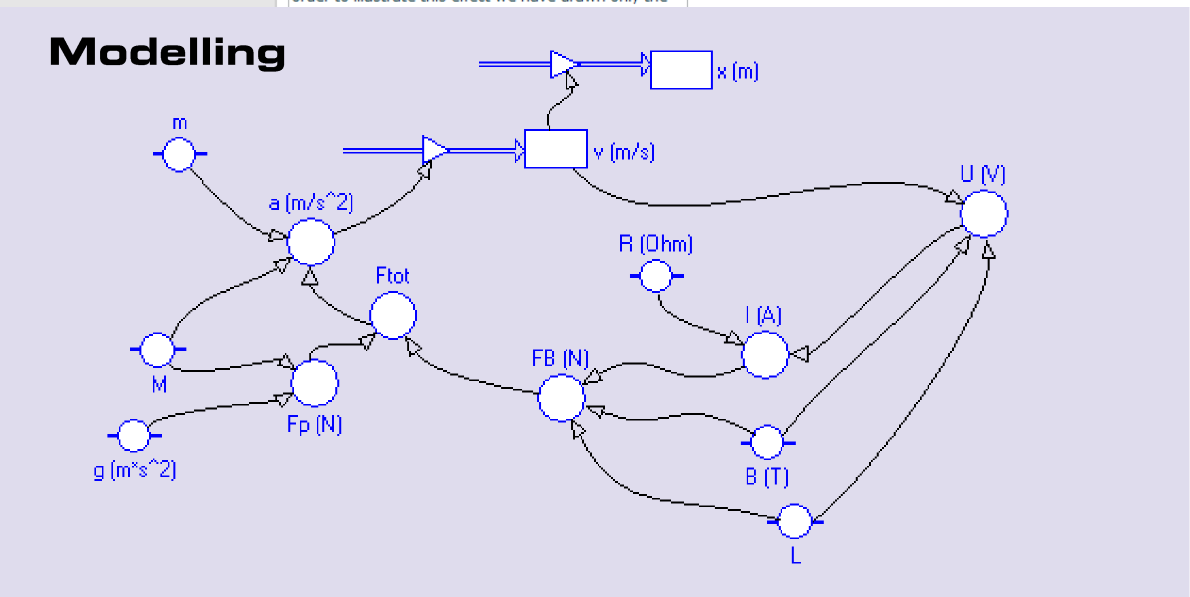

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Contact

Please direct questions and comments about this publication to
mosem2@simplicatus.no

Title

MOSEM² Teacher Guide

MOdelling and data acquisition for continuing vocational training of upper secondary school physics teachers in pupil-active learning of Superconductivity and ElectroMagnetism based on Minds-On Simple ExperiMents

In memory of
José Miguel Zamarro
† 22 March 2011

Online learning resources

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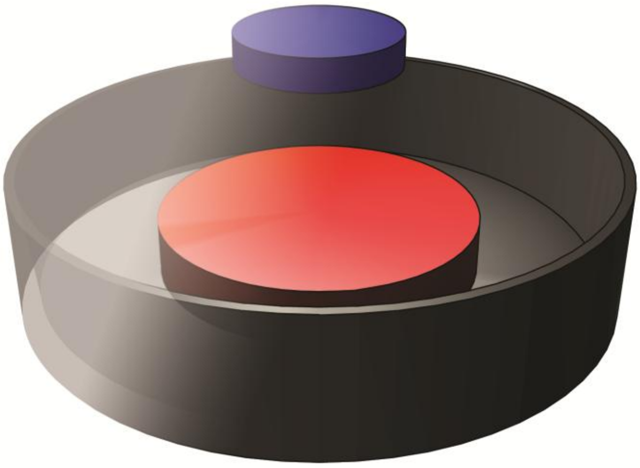
MOSEM² Teacher Guide



MOSEM² = MOSEM • MOSEM

MOdelling and data acquisition for continuing vocational training of upper secondary school physics teachers in pupil-active learning of Superconductivity and ElectroMagnetism based on Minds-On Simple ExperiMents

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SRD

Education and Culture DG

Lifelong Learning Programme

Table of contents

Project contributors

Teacher Guide

Work package leader

Tomasz Greczyło

Editors

Vegard Stornes Farstad
Tomasz Greczyło
Gren Ireson

Authors

Frederic Bouquet
Ewa Dębowska
Francisco Esquembre
Vegard Stornes Farstad
Tomasz Greczyło
Gren Ireson
Ewa Kędzierska
Libor Koniček
Marisa Michelini
Nadezhda Nancheva
Wim Peeters
Gerhard Rath

Photographs

Frederic Bouquet
Vegard Stornes Farstad
Libor Koniček
Josef Trna

Illustrations

Frederic Bouquet
Francisco Esquembre
Vegard Stornes Farstad
Tomasz Greczyło
Ewa Kędzierska
MOSEM project
SUPERCOMET project
SUPERCOMET 2 project

Project Management

Work package leader

Vegard Stornes Farstad

Main contributors

Eva Charlton
Aasrun Engstrøm
Kristin Granberg Kristoffersen
Morten Sandberg

Teacher Seminar

Work package leader

Wim Peeters

Main contributors

Tomasz Greczyło
Leopold Mathelitsch
Marisa Michelini
Gerhard Rath
Rossana Viola

Modelling

Work package leader
Ewa Kędzierska

Main contributors
Frederic Bouquet
Gren Ireson
Marisa Michelini
Lorenzo Santi

Simulations

Work package leader
Francisco Esquembre

Main contributors
María José Cano
Tomasz Greczyło
Wim Peeters
Marisa Michelini
Alberto Stefanel
†José Miguel Zamarro

Data Acquisition

Work package leader
Libor Koníček

Main contributors
Tomasz Greczyło
Ewa Kędzierska
Marisa Michelini
Nadezhda Nancheva
Wim Peeters

Evaluation

Work package leader
Gren Ireson

Main contributors
Tomasz Greczyło
Marisa Michelini
Nadezhda Nancheva
Wim Peeters
Gerhard Rath

Valorisation

Work package leader
Wim Peeters

Main contributors
Frederic Bouquet
Vegard Stornes Farstad
Tomasz Greczyło
Marisa Michelini
Nadezhda Nancheva
Gerhard Rath
Morten Sandberg

Photos/Videos

Work package leader
Josef Trna

Main contributors
Frederic Bouquet
Ladislav Dvorak
Vegard Stornes Farstad
Petr Novak
Gerhard Rath
Marta Svobodova

Partner organisations and participants

P01 Simplicatus Research and Development AS, Norway (Contractor)
Vegard Stornes Farstad, Aasrun Engstrøm, Morten Sandberg, Eva Charlton, Kristin Granberg Kristoffersen

P02 Karl-Franzens-Universität Graz, Austria
Leopold Mathelitsch, Gerhard Rath, Stefan Giuliani, Bernhard Falle, Florian Kittler, Helmut Lambauer, Heimo Latal, Josefa Latal, Eveline Monschein

P03 PONTOn VZW, Belgium
Wim Peeters

P04 РУСЕНСКИ УНИВЕРСИТЕТ (Ruse University), Bulgaria
Nadezhda Nancheva, Parvoletka Docheva

P05 Masarykova Univerzita, Czech Republic
Josef Trna, Ladislav Dvorak, Petr Novak, Gabriela Hlozkova, Jitka Sedlackova, Jindriska Svobodova, Marta Svobodova, Eva Trnova

P06 Ostravská Univerzita v Ostravě, Czech Republic
Libor Koniček, Erika Mechlova, Jana Janoscova, Milan Jurček, Zlata Skripová

P07 Universidad de Murcia, Spain
Francisco Esquembre, †José Miguel Zamarro, María José Cano, Angeles Martínez Cegarra, Rafael Chicón, Raquel Gras Gil, Ernesto Martín, Leonor Deltell Navarro, Isabel M. Solano, Maria Paz Prendes

P08 Université Paris-Sud 11, France
Frederic Bouquet, Julien Bobroff, Anne Frescaline, Brahim Kasmi, Gregory Maggion, Sonia Miranda, Fatima Zouaoui

P09 Università degli studi di Udine, DIFA e CIRD, Italy
Marisa Michelini, Lorenzo Santi, Alberto Stefanel, Rossana Viola, Giacomo Bozzo, Elena Ceccarelli, Cristiana Compagno, Giovanni Michelutti, Filippo Pascolo, Emanuela Pividore, Domelio Da Ru, Alberto Sabatini, Giorgio Salemi, Martina Scrignaro, Stefano Vercellati, Silvia Zuccaro

P10 AMSTEL Instituut, University of Amsterdam, Netherlands
Ewa Kędzierska, Ton Ellermeijer, André Heck, Leentje Molenaar, Frank Schweickert, Peter Uylings

P11 Uniwersytet Wrocławski, Poland
Tomasz Greczyło, Ewa Dębowska, Jan Chrzanowski, Bożena Paluch, Halina Paluch

P12 Nottingham Trent University, UK
Gren Ireson, Louise Rhodes

P13 BRG Kepler, Austria
Gerhard Rath, Stefanie Kerschenbauer

P14 Sint-Gabriëlcollege Boechout, Belgium
Marleen Bastiaenssen, Marika Van Osselaer

P15 Geo Milev English Language School, Bulgaria
Stefka Velichkova, Pavlina Angelova

P16 Matični Gymnázium Ostrava, Czech Republic
Petr Smyček, Adam Draqon, Tomáš Fismol, Zdeněk Maník

P17 Wichterlowo Gymnázium, Czech Republic
Antonín Balnar, Libor Klubal, Petra Kňurová, Jan Netolička, Michal Vavroš

P18 IES Juan de la Cierva y Codorníu, Spain
Miguel Cañizares

P19 CPC Santa María del Carmen, Spain
Maria Carmen Martínez Prieto

P20 Liceo Scientifico Giovanni Marinelli di Udine, Italy
Riccardo Sangoi, Riccardo Giannitrapani, Luigi Lanzoni, Giorgia Lauzzana, Tizianosandro Lenisa, Cristina Moschetta, Carla Querini, Anna Maria Rossi

P21 Liceo Scientifico Torricelli, Italy
Diego Gottardi, Barbara Boccagni, Gianpaolo Fedele, Luciano Giudilli, Lara Magnago, Paolo Mainardis

P22 Bonhoeffer College, Netherlands
Peter Uylings, M. de Groot, A. Moor, M.M.T. Nievelstein

P23 Lillestrøm Videregående Skole, Norway
Tor Nakstad, Helge Bratland, Trond Ekern, Todd Nore

P24 VZW DKO, DPB Antwerpen, Belgium
Jan Baeten, Wim Peeters

P25 Vereiniging Leerkrachten Wetenschappen VZW, Belgium
Roosje Van den Driessche, Marc Beddegenoodts

P26 NITO, Norway
Kim Sørensen, **Erik Prytz**

P27 Tekna, Norway
Iver Hille, Kåre Rygg Johnsen, Terje Olav Moen, Lene Nordrum, Tove Rodahl, Cathrine Roksvåg

P28 Nordnorsk Vitensenter, Norway
Anne Bruvold, Hallvard Figenschou, Robert Kamben

P29 Utdanningsforbundet, Norway
Stig Brusgaard, Rikke Bjurstrøm, Jan Olav Bruvik

P30 Polskie Stowarzyszenie Nauczycieli Przedmiotow Przyrodniczych, Poland
Piotr Felski, Elżbieta Kawecka, Dorota Rutecka, Józefina Turło

Introduction

Background

Europe lacks competent physics teachers – driving a negative feedback loop hat 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].

Conferences[2] and studies[3] have pointed out that science education needs to employ the use of models – mental models and mathematical models – in order to strengthen the cognitive and affective understanding of the concepts that need to be constructed by the learners. The PHYS 21 project[4] shows that many teachers do not share the view of physics as a set of models describing the real world.

A modelling approach in physics teaching need to focus on how teachers view science itself and the process of learning physics, not only on teaching materials. Teachers emphasize conceptual learning also when working with mathematical models, and they found it difficult to use the modelling approach in other topics than mechanics[5]. Another study[6] identified "a need to extend teachers' knowledge about the use of models and modelling in teaching scientific inquiry and the nature of science." A study[7] also showed that teachers need training in the use of data logging.

About the Project

The MOSEM² project aimed to improve this situation by promoting lifelong learning in physics and pedagogy for science teachers at the upper secondary level by applying a Minds-On approach to teacher training and physics learning to the modelling approach. We produced a teacher seminar, this teacher guide and new learning materials for modelling, simulations and data acquisition activities. We used equipment available on the market as well as equipment developed by the partners in previous related Leonardo projects.

The project builds on the foundations of several collaborations in national and/or European projects, most recently the MOSEM and SUPERCOMET 2 projects, which are the direct sources of the project ideas and consortium. The previous projects focussed on Minds-On conceptual learning, while MOSEM² applied the Minds-On approach to modelling, simulations and data acquisition.

The MOSEM² consortium included leading European physics educators that are frequent contributors at international conferences for physics education.

[1] Smithers and Robinson, 2008.
[2] E.g. the GIREP 2006 conference on modelling
[3] Guttersrud, 2008; Gilbert, 2004; Greca & Moreira, 2002 and Hestenes, 1987
[4] Angell et al., 2007
[5] Angell et al., 2008
[6] Henze, van Driel & Veerloop, 2007
[7] Danielsen, 2008

Several partners held presidencies or international scientific advisory capacities of international organisations like GIREP, MPTL and ESERA. As valorisation partners, the consortium included 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.

Minds-on Learning and Teaching

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 misunderstandings, pre-instructional beliefs, untutored beliefs, naïve theories, naïve ideas, intuitive ideas, prior conceptions, preconceptions, alternative frameworks or misconceptions. 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[8], many studies focusing upon children's alternative conceptions were carried out from the 1970s onwards[9]. Many studies[10] 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[11].

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[12] and within different cultures[13].

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 focussing upon student teachers' concept mastery[14]. Palmer (1997) found that even after instruction, significant proportions of student teachers held on to their alternative conceptions. This is in agreement with an earlier study by Clement (1982). The more mature a student is, the more consistent he or she is likely to be in the application of an accepted idea.

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[8] for example Hancock, 1940
[9] for representative reviews of such research see Driver & Easley, 1978; Driver & Erickson, 1983; Duit, 1987 and McDermott, 1984
[10] such as those of Bar et al., 1994 and Brown, 1994
[11] for examples within the field of chemistry, see Schmidt, 1997 and Taber, 1996
[12] Kaiser et al., 1986 and Elaine Reynoso et al., 1993
[13] Bogdanov & Viiri, 1999 and Van Hise, 1988
[14] Willson and Williams, 1996; Schoon and Boone, 1998

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 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.

Within the MOSEM² project we advocate the attendance at a teacher seminar prior to using animations, simulations, modelling and data acquisition. 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.

CASE and Minds-On activities

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 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[15]. 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[16].

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 developed in MOSEM² and described in this Teacher Guide 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. To use the CASE terminology, we would see our approach as meta-hands-on.

This we will call Minds-On science teaching.

[15] Adey and Shayer, 1994; Shayer, 2000
[16] Shayer, 1996

Results

The tangible results of the MOSEM² project include Activity descriptions and data files for modelling, simulations and data acquisition. A novel demonstration device for the properties of superconductivity has been developed, based on the MOSEM High-Tech Kit. Complementing previous texts from the SUPERCOMET 2 project, a new explanation of the physics behind superconductivity is included in this Teacher Guide.

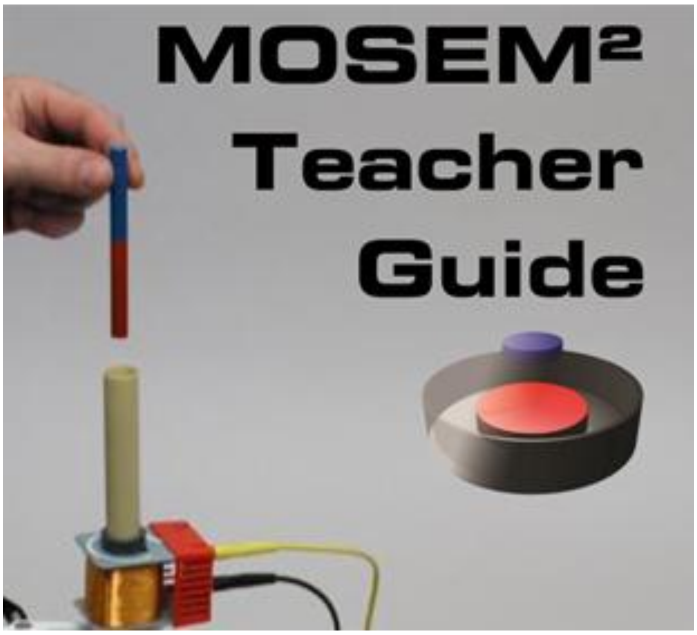
Teacher Seminar

The aim of MOSEM² is to improve the quality of physics teaching and learning in Europe, and therefore the key deliverable is a Teacher Seminar for in-service and pre-service teacher training.

Teacher Seminar in Ruse, Bulgaria. Photo credits: Nadezhda Nancheva

The basic premise of this seminar is cooperative learning and professional development, not only focusing on content related to the other deliverables. Participating teachers will experience first-hand the resources presented by the project, as well as an approach for assessing their own professional development.

Teacher Guide

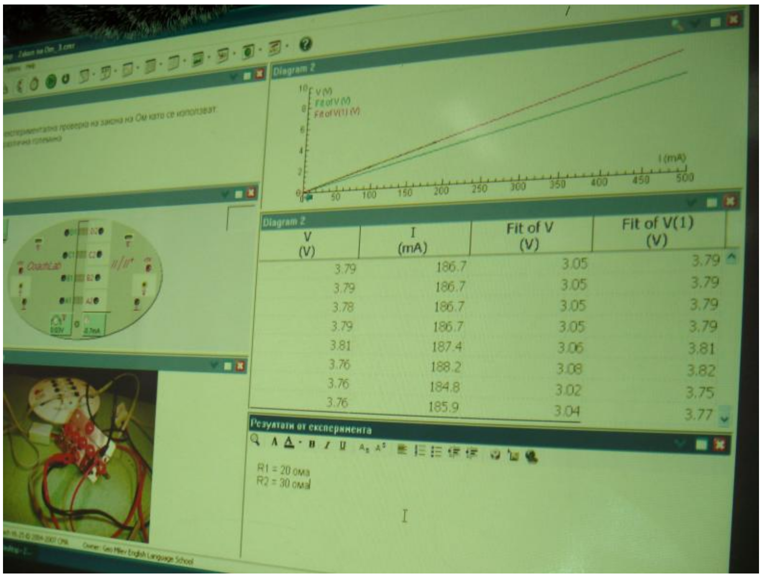


The MOSEM² Teacher Guide is intended to outline the pedagogical rationale for using the project outcomes. It suggests effective ways of using them in the classroom, as a part of everyday teaching, in stand-alone mode or in combination with experimental kits and multimedia tools.

The Teacher Guide is an integral part of the Teacher Seminar, being the centrepiece of the project support materials. Moreover it contains an explanation of superconductivity from the basic principles of quantum mechanics especially written for the project, courtesy of leading researchers in this exciting field of physics. It also contains resources for evaluation of the learning outcomes for students and teacher seminar participants.

ICT tools

In order to be relevant for current physics teaching practice, project activities are technology based. We make use of ICT-based materials to improve the teaching of electromagnetism and superconductivity. We provide tools and methods to help teachers to understand how each type of ICT-based material can improve their everyday teaching.



The MOSEM² project promotes discovery learning allowing students to play an active role in their learning by becoming involved in hands-on, minds-on activities as well as presents several of different teaching approaches.

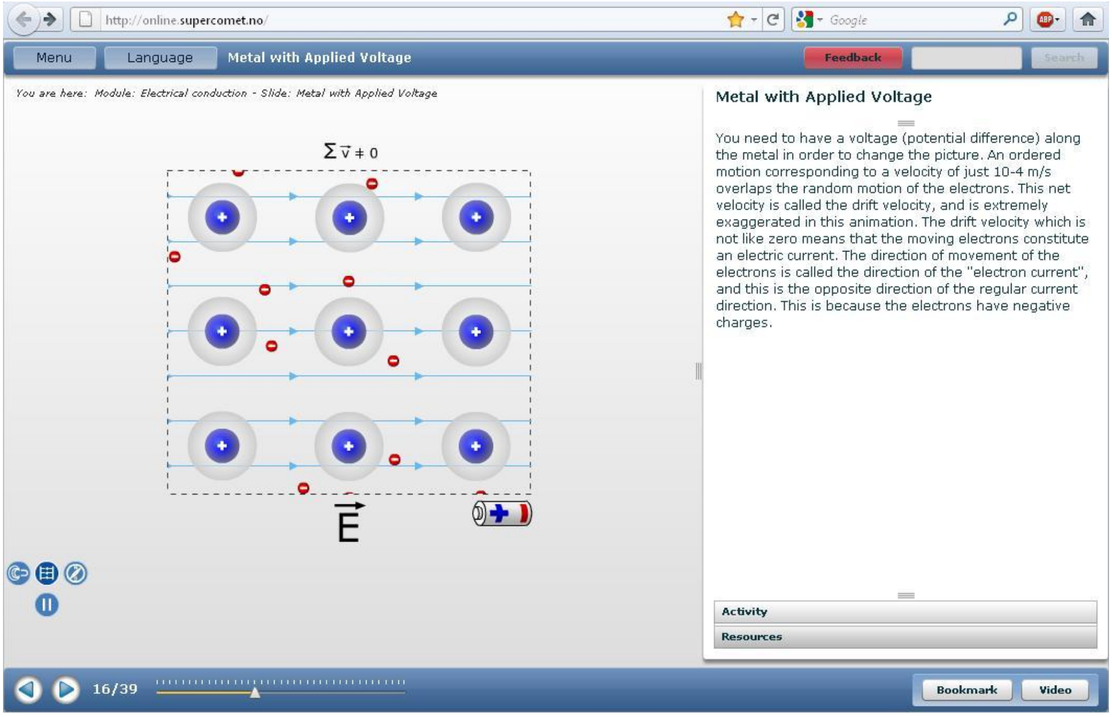
We do not wish to tell teachers how to use ICT during their lectures but we provide a variety of different material educators can conjugate to adapt to their teaching needs and approach.

We emphasize the modelling view of physics in using these materials. The project also adds a European dimension by developing material which can be used in different national curricula. Among a number of ICT tools we make extensive use of the types described below. These are not mutually exclusive – they can overlap and complement each other.

Electronic materials (e.g. Coach 6 Modelling Activities, Easy Java Simulations, Coach 6 Data Acquisition Activities, this Teacher Guide, selected videos and other support materials) can be downloaded from mosem.eu.

Animations

An animation is a computer visualization or video (in a broad sense: moving images created with the use of computers) that displays a phenomenon without a real computation behind it.

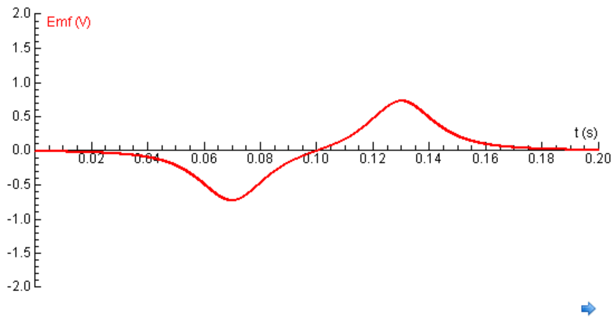


Besides many entirely described attributes of an animation made for educational purposes it should be qualitative right and easy to run.

A student primarily watches such an animation – the teacher encourages learners to sit down and watch a nice, qualitative visualization which explains by visual clues 'how things work'. Therefore interaction driven by an animation is very limited.

Creating such MOSEM² activities we used SUPERCOMET 2 animations or MOSEM videos where a first visualization helps introduce or motivate a topic. The animations are available at animations.mosem.eu and videos at youtube.mosem.eu.

Modelling



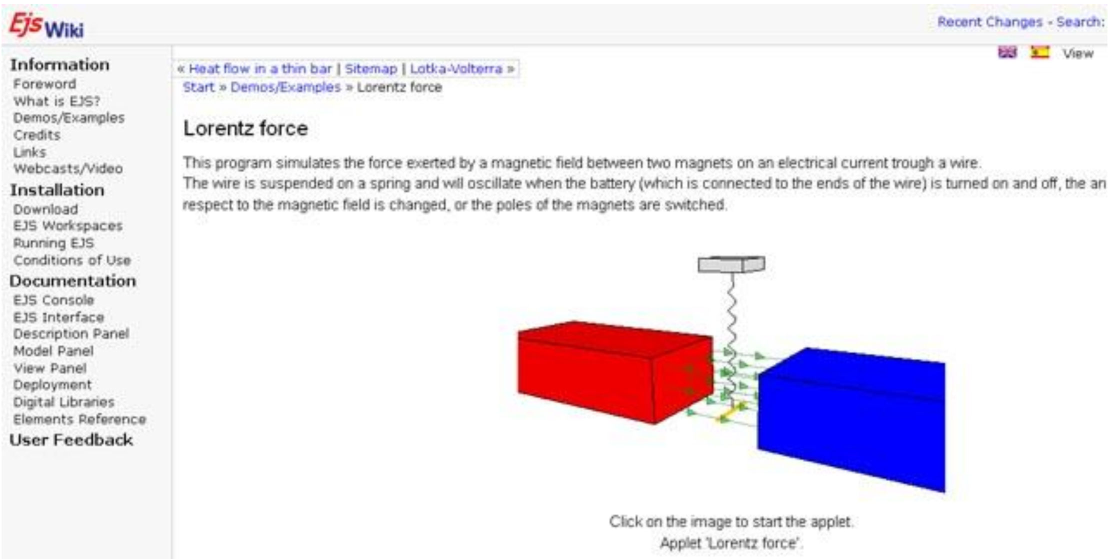
By modelling we understood a computer-based activity where the user creates or modifies an existing model – building or introducing changes to a computer algorithm that produces data or a simulation of a phenomenon.

MOSEM² modelling activities are designed to make your students understand how things work by having them actually work with the model, combining physics, math, and technology. To achieve the goals we favor modelling whenever the complexity of the model can be reasonably understood by average high-school students. Therefore we used Coach 6 – an educational electronic environment that demands low programming skills.

The new learning materials combine mathematical models, simulations and video analyses of simple thought-provoking tabletop experiments, supported by electronic and printed materials comprising additional videos, animations and text.

Simulations

A simulation is a computer program that uses an internal model to produce data and visualization, as accurate as possible, of a simulated phenomenon. Advanced simulations are used every day to predict weather, stock prices and practically every other variable important for science and commerce.



In addition to a number of generally important attributes, a simulation intended for educational purposes should be quantitatively right, interactive and allow the learner to vary one or more parameters easily. Students primarily work with a simulation – this way the teacher allows the student to explore a phenomenon by running the computer program with different parameters and/or initial conditions, and subsequently analyzing/visualizing the quantitative outcomes of the program.

The Easy Java Simulations (EJS) platform was used for developing a number of new simulations related to the topics covered by SUPERCOMET 2 animations and qualitative activities from the MOSEM kits. These simulations allow the learner to explore actively the key concepts of electromagnetism presented by the previously developed animations.

The EJS environment allows creating simulations which require a model considered to be too difficult to be understood by a student and therefore not suitable for a modelling activity. We use EJS because it leverages the creation and inspection of programs as compared to pure programming. A detailed description can be found in the file "*introduction_EJS.pdf*" which can be downloaded from mosem.eu.

Data Aquisition

Data Aquisition workshop in Ostrava, Czech Republic. Photo credits: Libor Koniček

MOSEM² Data Acquisition activities are created to encourage student to control and measure real physical phenomena by collecting data from equipment connected to the computer or from analyzing real movie showing a physics situation. To gather and elaborate data students use Coachlab II sensors directly interfacing with the Coach 6 interface and environment for analyzing the collected data using models.

In this way learners can produce and collect their own data to help connect observations and predictions made by their models in order to verify or falsify hypotheses proposed in advance.

The extended description of Coach modelling and data acquisition tools can be found in the file "*guide_coach_6_3.pdf*" which can be downloaded from mosem.eu. Other hardware/software has been used for some activities.

Möbius track

The MOSEM² project also developed a unique demonstration device for the special properties of superconductors. An extension of the materials and activities in the MOSEM High-Tech Kit, a superconducting magnetically levitated train follows a track shaped like a Möbius band. The special mathematical property of such a Möebius band is that it has only one surface.

Möbius-shaped magnetic track for levitating train. Photo credits: Vegard Farstad

Physically this differs from a regular train track in that it curves around its own axis, so the train cannot simply levitate vertically above the track, it also needs to counter the gravitational force when it is moving horizontally or upside down with regard to the track itself.

There is only one way such magnetic levitation at all angles can be accomplished with a single flat track, without the use of additional complicated steering tracks. That is by using the phenomenon of superconducting magnetic pinning, where magnetic flux lines anchor the superconductor in the train to the magnets in the track with a force strong enough to overcome gravity at all angles. It is not simply an unstable repulsive force as can be used for vertical-only levitation provided additional steering tracks are used for stabilization.

The force caused by magnetic pinning keeps a fixed distance and direction between the superconductor and the magnets, allowing stable levitation of the train whether it is moving sideways, upside down or simply above the track like other levitating trains.

Impact

The short term impact will be on the local and regional level, as partner schools and valorisation partners try out the MOSEM² materials in connection with the Minds-On Kits developed in MOSEM and the online learning modules developed in SUPERCOMET 2. Future follow-up projects implementing results in larger numbers of schools in different countries will have a broader impact.

The network of users extends beyond the MOSEM² partnership due to the family of related projects that has established a pool of participants in 15 countries. International collaboration including the use of social media and building an online community will connect teachers in different countries, allowing them to share experience, teaching materials and methods as well as improving language skills and cultural understanding.

Teacher Seminar

Teaching with MOSEM² materials

A teacher seminar does not only transfer knowledge to teachers, but can aim at different goals, at different levels of teachers' professionalism.

For MOSEM and MOSEM² the first type of teacher seminar is very content oriented, and the additional value is that new kinds of teaching methods are used. 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 strictly (apart from local adaptations). Intellectually, the teacher remains passive in the sense that he absorbs ideas. This type of Teacher Seminar was extensively described in the MOSEM Teacher Guide.

The second type, characteristic for MOSEM², is 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.

EFQM model

A novel approach to a teacher seminar preferred is via the EFQM model, adapted to education and in particular groups of learners, like participants in MOSEM². To help organizations to continuously improve and achieve higher levels of performance, EFQM

- assesses their performance
- provides them with networking and mutual learning experience
- offers education and learning opportunities
- recognizes their achievements
- supports their implementation of best in class tools and practices.

The EFQM Model distinguishes five different development phases for an organization:

Phase I: Activity oriented:

- Each individual teacher wants to execute its work as good as possible;
- Professional skills are appreciated and will be supported with training courses in the school;
- In case of complaints the organization will try to solve the complaint.

Phase II: Process oriented:

- Control of primary processes: teaching, collaboration
- Independent process steps are identified, tasks, responsibilities and authority of individuals is known: groups of teachers meet and agree
- Performance indicators are used to manage the organization: who does what and when?
- Improvement of processes based on deviations of the normal: what to do when it does not work out as planned?

Phase III: System oriented:

- All levels in the organization continuously and systematically work on improving the whole organization: all teachers in a group think on how to be sure that the goals will be reached
- The Deming Circle (Plan-Do-Check-Act) is applied on all primary, supporting and managing processes: every partner/teacher reflects on a regular base on the progress and acts correcting if possible.
- Client focus is dominant for policy: all efforts in view of better learning for students
- Focused on preventing problems instead of dealing/solving problems: anticipate on context based issues (class room, students, prior results, attitudes and skills of students, etc.)

Phase IV: Chain oriented:

- With partners (European partners, schools in one country, school heads, colleagues and also students= chain) the aim is to create maximum value added in the chain: improve the quality of the context/course/lessons/materials continuously
- Within the chain it is decided which partner is most suitable for a certain task;
- Managing systems of all organizations in the chain are combined;
- Innovation is the primary focus.

Phase V: Transformation oriented:

- Focus is to be the top in education; definition of “top” can vary: results oriented, social oriented,
- Based on the long term vision certain activities are ended and new activities are started;
- Continuous organizational development based on the continuously changing environment;
- Co-operation with the partners in the chain.

A school has to determine in which of the five phases described above it is in and what potential developments are possible. Then the management team has to decide if it wants to continue with developing the school to the next phase[17].

Teacher professionalism

Five stages correspond to five levels of teacher professionalism which determinate the type of an appropriate teacher seminar. The below descriptions were prepared to assist teachers in learning about their stage[18].

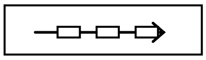
If the teacher chooses the Activity type teacher seminar:

- the teacher subscribes yourself for seminars

[17] ww1.efqm.org/en/tabid/270/default.aspx, www.ba2c.com/documents/Informationefqm.pdf
[18] profile idea and logo's: DKO vzw, Teacher Coaching Organization, Antwerpen

- the teacher wants to get ready to use teaching materials (content and new teaching methods); the more support materials , with good teacher guides the better
- the teacher wants to hear new ideas and evaluate them
- the teacher wants to learn to use the new materials (knowledge, skills)
- the teacher is not sure that will use the materials in the class
- the teacher does not have time to start from scratch in making own lessons.
- the teacher likes a good and clear structured teacher seminar, with correct timing

If the teacher chooses the process type teacher seminar:

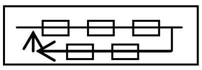


- the teacher is responsible for the implementation of new ideas, also for the way how
- the teacher talks to his colleagues at school
- the participants need to prepare trainings well
- teachers discuss learning paths, educational materials, experiments. - the teacher reflects on how to do things in the class room, what is necessary to make this a success
- the teacher finds solutions to his questions and problems with the active help of the trainer and the group.
- the teacher is willing to become a learner, but needs help from equally regarded colleagues.
- all participants learn in a responsible way.

Recommendations for authors of teacher seminar sessions

- the trainer uses strategies to order and organise the discussions
- trainings are based on equality between all participants, the teacher trainer included
- interaction and discussion are crucial
- all participants must be active
- on the long term, implementation of his knowledge (and the teaching materials) 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.

If the teacher chooses the system phase (teacher as developer in group) type teacher seminar:

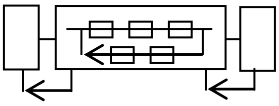


- the teacher already has competencies on all levels: knowhow, skills and attitudes to tackle new challenges
- the group discussions and the materials presented are regarded as an opportunity to improve her/his competencies
- the teacher is already a learner.
- the teacher will implement at least the usable materials, no matter what happens
- the teacher uses the new materials as part of a bigger plan for improvement of his lessons

Recommendations for authors of teacher seminar sessions

- aim more at long term vision
- aim at coherency between curriculum and lessons, and vertical and horizontal learning lines
- are meant for a coherent group (for example of one school)

If the teacher chooses the chain phase (teacher as manager of (her/his) new learning) teacher seminar:

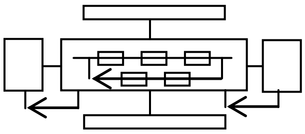


- teachers' discussion of materials are rather short.
- teachers read materials offered (cards for experiments, multimedia materials)
- they decide if they implement new things in the class room
- they assemble new lessons (materials, strategies and methods included)
- groups of teachers meet regularly and discuss with the responsible
- they present the self made materials and discuss with colleagues
- teachers modify step by step their Activity
- teachers are capable of integrating (collect, evaluate, adapt and implement) all new materials themselves
- this kind of teacher gets easily inspired by excellent teachers

Recommendations for authors of teacher seminar sessions

- 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.

If the teacher chooses the excellence phase (total quality, leadership) teacher seminar:



- this phase cannot be trained by others; self learning
- enhanced individual competencies
- the teacher is a trainer, developer himself; professional learner
- she/he is aware of educational research in his field
- she/he pilots methods for testing and getting experience
- the teacher focuses is to be the top in education; definition of "top" can vary: results oriented, social oriented
- based on the long term vision certain activities are ended and new activities are started
- the teacher takes part in continuous organizational development based on the continuously changing environment and co-operation with the partners in the chain.

Recommendations for authors of teacher seminar sessions

- the teacher attends trainings of other excellent teachers to compare and to get inspired
- she/he attends seminars and conferences on the highest level of his profession

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, so that they can become independent of coaching help, and collaboration has become structural.

Summary of professional development levels

- *activity* = willing, being there, only for "consumption" of materials, on himself, only personal, almost no networking;
- *process* = in view of close colleagues, open for discussion, a bit modest, "easy" adaptations, network within the school/ immediate environment;
- *system* = perfect colleague, collaborating, thinking in view of class, school and future, extended network, participating, not too engaged however;
- *chain* = eyes wide open, a lot of energy, vision, adaptations, wide network of colleagues, highly engaged;
- *excellence* = international network, developer, perfectionist, lecturer, leader.

Teacher questionnaire

The following questionnaire, containing an indicative list of questions, was developed in the project to assist teachers in getting an idea of the profile the teacher has. This affects the type of seminar the teacher wants to attend: active, process, system, chain or excellent.

Questions to answer. A positive answer allocates the responding teacher at a certain proficiency level indicated on the right.	**Yes**	**No**	**Profile check**
I like discussions with my colleagues			**2**
I mainly hope to get ready-to-use worksheets for students			**1**
I want to hear how to do things (teach topics, use materials)			**1**
I go to a teacher training session to train my experimental skills			**1**
My lessons change every year, I am continuously trying to improve them			**3**
In general I have my own interpretation of the curriculum and act according to it, even if this is a little "outside the lines"			**4**
If the trainer gives me a web address I normally visit it			**2**
Afterwards, I almost never look at the materials I got from a training session			**0**
I go to a training session to hear what materials are best to use			**1**
A session must be given by the trainer, not by the participants			**1**
I like sessions best if I can participate in an active way; exercises etc.			**2**
If I am attending a session, I prepare for it (study the topic beforehand)			**3**
If I attend a session, I take teaching materials home afterwards			**1**
If I am going to attend session, I take own teaching materials with me to that session			**4**
It has happened before that I contact the session leader afterwards			**4**
I hate it if someone would see and read my teaching materials			**1**
I love to have colleagues reading my teaching materials, hoping for feedback			**3**
My priority in attending a teacher seminar is to know where teaching materials can be found			**1**
All teachers from my school prepare parallel exams together			**3**
In general I stick to the lessons as they were last year: they are good			**1**
I do not like to interfere during a session			**1**
If I get materials from others, I give them feedback			**3**
In general I follow a certain textbook closely, it is better for the students (structure)			**1**
If I get materials from colleagues, I find it mostly not usable			**1**

After discussions during a seminar often I regret that I cannot go on working on the topic with other colleagues (even in a different setting)			3
I meet on a regular base with colleagues from my own school			2
I have given training sessions yourself more than once in past five years			5
If I attend a session, I take my memo stick with me			1
Sometimes I think that the materials and information presented are below the level of my own teaching materials			3
During a teacher training session I never raise my hand			1
After a training session I have often developed my own lessons based on the materials I got			2
At the moment I am in contact with at least one colleague from another school to exchange lessons			4
I have never wanted to go to a conference in my own country			3
At the moment I am in contact with at least one colleague from my own school to exchange lessons			3
I do not go to sessions on topics I do not like to teach			1
I select teacher trainings sessions carefully in view of curriculum matters			4
I consider yourself as "reasonably creative" as far as teaching is concerned (materials, methods)			3
I experiment with teaching methods on a regular base			4
I always buy physics' experiments, I have never made one yourself			1
I am always looking for new ideas, and that makes I change about 10% of my lessons every year			4
I have lots of materials already, but implementing did not happen because of lack of time			2
I know a lot of colleagues in science, but there is no contact on the professional level			1
I attend training sessions because the head of school asks me to			0
I have given teacher trainings at several occasions (schools, conferences, etc.)			5
At a teacher seminar on a new topic I expect to get all materials			1
I love to hear an expert during a presentation on a special topic			1
During a training session I want to explain my own vision on teaching			1
During a training session I want to learn how to improve my teaching			1
I always want to learn more about my discipline, listening to specialists			1
Using new materials is OK, provided that I get all support materials			1
I use new materials only when they are in full agreement with the curriculum			1
I use only materials directly connected to a text book during my lessons			1
I like to find solutions to questions myself			2
I am an active member of a teacher association			3
I always discuss new materials with colleagues at school.			2
I deliver all materials I get from a session to my colleagues at school			2
I often upload my materials to the school server for sharing with colleagues			2
I am a member of a teacher association			2
I really think that my teaching always can be improved			1
I often upload materials to a national server for sharing with colleagues nationwide			4
I am a leading member of a teaching organization			5
I have set up teacher trainings for an organization, apart from school several times.			5
I upload and download materials from a nationwide server at least 8 times a year			4
I manage upload and download materials from a nationwide server			5
I upload and download materials from a nationwide server at least 2 times a year			3
I manage upload and download materials from my school server			3

I go to teacher seminars even if the topic is not directly linked to the curriculum			4
I change given materials to serve my own needs			2
I have lead a discussion of teachers at school several times.			2
I have ever lead a discussion of teachers coming from different countries			4
I have ever lead a discussion of teachers coming from all over the country			4
I have taken initiative to bring together a group of teachers to discuss educational topics already at least once			4
I do think that we must learn our students to work together in the class room			3
If a student asks a question, I only really answer it if it is linked to the topic			1
I often answer to an interesting question too enthusiastic so that my lesson plan is ruined			2
After a lesson I write down some remarks for myself for next time			2
If an experiment fails, I go to the next item of the lesson			0
If an experiment fails, I discuss this with the whole class			1
If an experiment fails, I improve it do it again next time			1
I accept only new materials if they are in line with what I am doing already			1
I think that the opinion of my colleagues on my materials is important, and I act consequently			3

Note: It was beyond the scope of the project to balance the items in this questionnaire – therefore it cannot be used to determine the proficiency level of a teacher by averaging the scores. In its current form, it is only meant to raise the awareness of the teacher's own professional practice. The authors recommend reducing the list to about 10 or 15 items for practical use.

Seminar sessions

The MOSEM² teacher seminar aims at finishing the cycle of professionalizing physics teachers. After initial seminars on SUPERCOMET 2 (stressing adapting active learning teaching methods) and MOSEM (stressing group learning and experimental skills, both for students and teachers), the MOSEM² teacher seminar stresses networking and collaborative learning by teachers, as well as self assessment on the way the teacher wants to learn (during a seminar).

Therefore the 2-session seminar starts with a questionnaire that encourages teachers to choose between the two types of seminar presented. In short the choice is between having a lot of guidance by the teacher trainer and the materials presented (Activity based) and a lot of independent learning in a group. (Process based). Every participant should be aware of this different approach towards teachers. Some of the materials are also ready for use by students. In a rather similar way, the materials are set up for students that need a lot of help (guidance) in planning, understanding, technical issues, scientific explanations as well as for students of a more advanced level being able to work in group, to plan, to set up experiments, to set up activities and to set up a research task.

The ideas are based on EFQM principles. During the teacher seminar also new insights are taken into account, as far as strategy towards teachers is concerned: red the Rapinen report and the text on the PCK method.

Both types of seminar of course offer/use materials made available by the MOSEM² project, but also by the previous ones, MOSEM and SUPERCOMET 2. After this introduction the rest of the teacher seminar shows three blocks, covering the three main issues of MOSEM²: modeling, simulation and data acquisition (real and video).

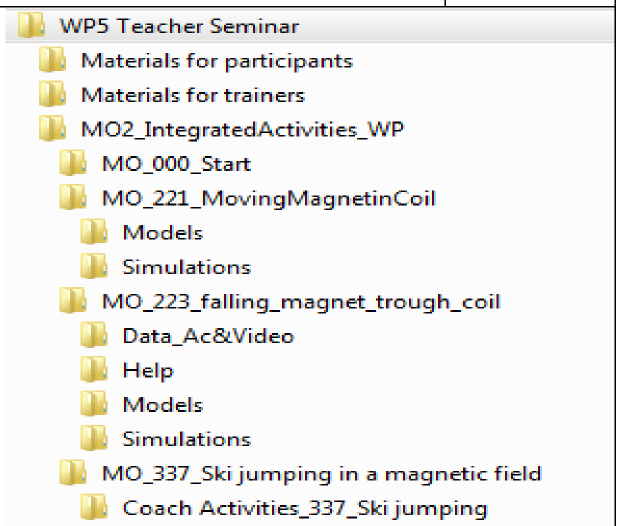
The three blocks are presented in two ways, adapted to the two types of learning: Activity (type A) based and Process (type P) based.

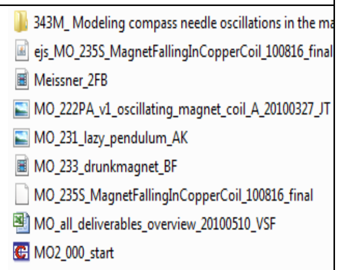
Since the physics content is based on previous projects, it is impossible to rehearse this: look at the teacher seminars of those projects. The beginning situation requires some initial work by the participant. Almost all of it is digitally documented.

Inherent to the Process profile is that these people meet a third time, exchanging the finalized materials and experiences of testing them in the class room.

Type A teacher seminar: Activity

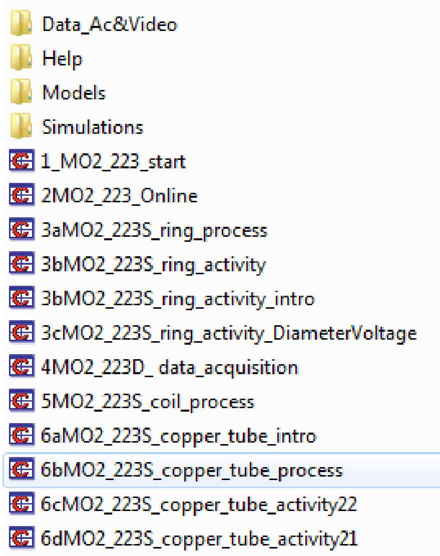
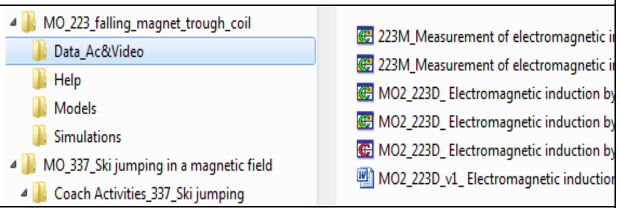
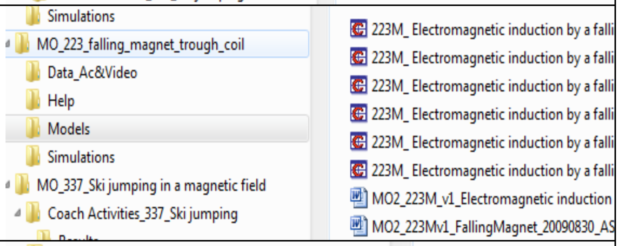
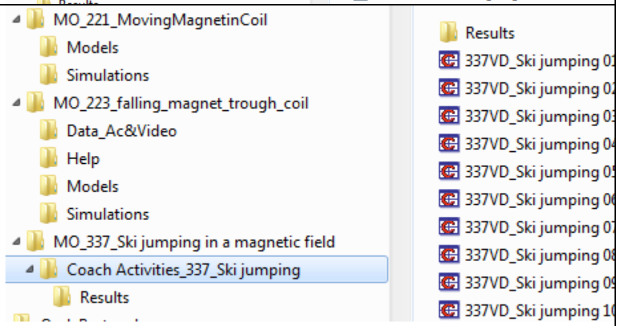
These teachers will be treated as learners that need guidance by a teacher trainer. They learn mostly individually. Planning and delivering knowledge is in the hands of the trainer. The trainer organizes discussions and exchange of knowledge. Their attitude is positive towards learning. They can be regarded as “a very good class”

Timing	**Goal**	**Activity**	**Materials needed *in italics* the file names to be found in one of the folders (see overview at the end of this section)**	**Remarks**
Prior to teacher seminar	- get well prepared teachers - minimizing introduction	- study the SUPERCOMET online application - study the MOSEM project - study teaching methods used	- SUPERCOMET online application - MOSEM materials: descriptions of experiments including minds-on questions, worksheets, video’s, pictures - MOSEM project family forum, website and repository - see files *MO_all_deliverables_overview_teacher_seminar_20100524_TG* and *MOSEM_WP5_DigitalGuideOfDigitalMeans_20100126_WP*	Focusing on MOSEM². it is impossible to add all previous trainings. Self study is basic and necessary
Invitation to teacher seminar	- teachers should do self study - teachers should bring their curriculum		Communicate MOSEM project family forum, website and repository	
For the teacher trainer	Understand the structure of the TS	- the TS consists of materials for the teacher trainers (study this in advance!), Materials for the participants and a series of Integrated activities for teachers. These are meant for the teachers, but, if they consider this usable for their students, it can be used for students too, provided some changes are made All activities are based on Coach PS: the Simulation activities can be transferred to another format, using Word and Excel for example.		

Teacher seminar A1				
10	Introduction - project fact sheet - connection to previous projects	- short presentation	-PowerPoint on the project family: *MO2_project_family_20110104_VE_WP*	
50	Professionalizing teachers: determination of type of seminar: type A or type P - make teachers aware that LLL is needed and how this leads to quality education - also that there are quality standards that apply to them - let them learn what priorities this quality thinking sets for teachers - split all teachers in two groups	- teachers should fill out EFQM questionnaire - give the correct answers - self assessment, given the answers: a teacher can summarize his sheet and determine for himself to what category number he wishes to belong - characteristics of all 5 levels of EFQM are given: it is stressed that all people only need to look to the next category to improve. Only improvement counts, not the status itself. Bottom line is: choose between Activity profile or Process profile	- questionnaire: *MO2_WP5_Teacher_Seminar_profile_teachers_quest_20100118Nott_WP* - overview of categories *MO2_WP5_What_is_EFQM_PONTOn_20110104_WP* - basic ideas behind EFQM (also look at *MOSEM_PCK teacher_SIF09_20091230_MM* and *Rapinen_quality of education*	- the teacher seminar will have two learning paths: one for Activity based learners, one for process based learners - the former need very much help MOSEM_WP5_Teacher_Seminar_profile_teachers_quest_20100116Nott_WP
30	Global information: resources available; organisation	Show crucial guides, files and other means to get access to resources	*MO_all_deliverables_overview_teacher_seminar_20100524_TG* and *MOSEM_WP5_DigitalGuideOfDigitalMeans_20100126_WP* Websites and repository	
Pause				
30	MO integrated activities learn materials, techniques and resources	Learn about the Coach environment Learn about the EJS environment	Activities in folder *MO_000_Start* , start with MO2_000_start	

60	Learn about the SUPERCOMET 2 online animations, slide 4 and 5 Learn how to work with simulations If a reasonable series is done it will be OK; it is NOT possible to do it all	*0_MO2_221_MagnetHorCoil_start* *1_MO2_221_Online* in folder *MO_221_MovingMagnetinCoil* *Start with 221S_MagnetHorCoil_intro, then 221S_MagnetHorCoil_activity_21a*, and after that, if the inherent structure is followed activities *22a, 23a, 21b, 22b, 23b, 31, 32, 33 follow, in that order.*	0_MO2_221_MagnetHorCoil_start 1_MO2_221_Online 221S_MagnetHorCoil_activity_3.1 221S_MagnetHorCoil_activity_3.2 221S_MagnetHorCoil_activity_3.3 221S_MagnetHorCoil_activity_21a 221S_MagnetHorCoil_activity_21b 221S_MagnetHorCoil_activity_22a 221S_MagnetHorCoil_activity_22b 221S_MagnetHorCoil_activity_23a 221S_MagnetHorCoil_activity_23b 221S_MagnetHorCoil_intro 221S_MagnetHorCoil_process ejs_MO_221S_StationarySolenoidMovingMagnet_101207 MO_221S_StationarySolenoidMovingMagnet_101207	For Activity oriented people the order is set. Everything is prepared, including tables etc. What skills are needed? - to have a minimum experience in working with Coach - or to be able to set up a table of datasets, with initial choices of independent parameter - to be able to analyze a set of data via the table and/or the diagram - to be able to formulate a conclusion
10	Discussion between participants	First impressions		

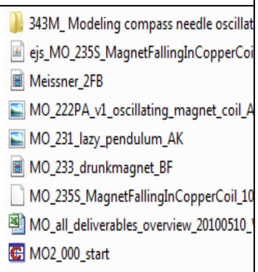
Teacher seminar A2			
10	Introduction: what did we learn last time	Discussion between participants	
30	Models: learn materials, techniques and resources	Look in folder Models in folder *MO_221_MovingMagnetinCoil*	221M. Electromagnetic induction by a moving magnet A with animation 221M. Electromagnetic induction by a moving magnet A 221M. Electromagnetic induction by a moving magnet B with animation 221M. Electromagnetic induction by a moving magnet B MO2_221M_Magnetization of a permanent magnet_20100120_PU MO2_221M_v1_Electromagnetic induction by a moving magnet_NonElab_201

50	Full integration of activities: data acquisition, simulations, modeling	Look in Folder MO_223_falling_magnet_thorugh coil Except for the file that starts with 3a, 5 and 6b (not meant for this group), all others should be carried out in this order		
Pause				
30	Special attention to data acquisition	Look in the folder and carry out *MO2_223D_ Electromagnetic induction by a falling magnet*		
20	Special attention to models	Look in the folder “Models” and study the models given		
20	Special attention to data video	Look in the folder “MO_337_Ski jumping in a magnetic field” and then in the folder “Coach Activities_337_Ski jumping”.		
20	Interactive evaluation by the teachers	Look in the folder “Materials for teachers”, the file *MOSEM²_WP8_Teacher_Seminar_questionnaire_20100120_GI*	Please send the results of this evaluation to both Wim Peeters and Gren Ireson. Thank you!	

Type P teacher seminar: Process

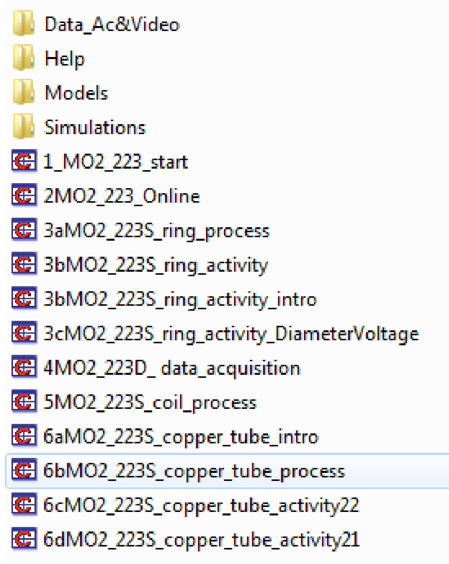
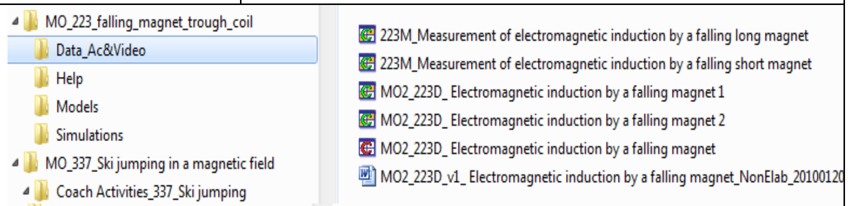
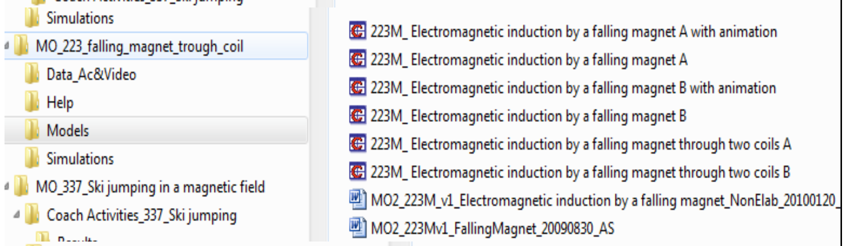
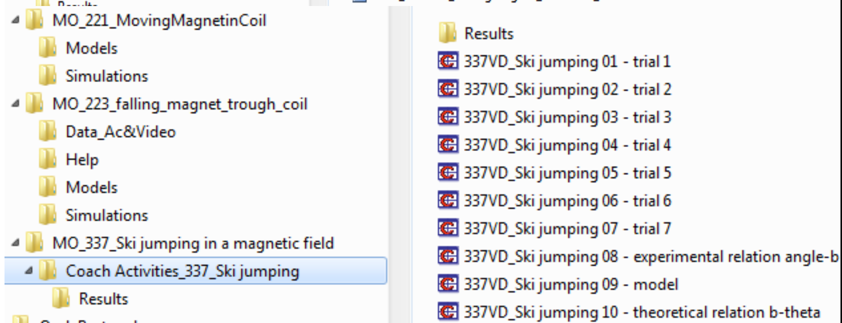
These teachers will be treated as professional learners that can organize themselves in groups, that can plan their learning time and that can allocate tasks to the most suited person of the group. Apart from that they discuss and exchange knowledge and learn from each other.

Timing	**Goal**	**Activity**	**Materials needed *in italics* the file names to be found in one of the folders (see overview at the end of this document)**	**Remarks**
Prior to teacher seminar	- get well prepared teachers - minimizing introduction	- study the SUPERCOMET online application - study the MOSEM project - study teaching methods used	- SUPERCOMET2 online application - MOSEM materials: descriptions of experiments including minds-on questions, worksheets, video's, pictures - MOSEM project family forum, website and repository - see files *MO_all_deliverables_overview_teacher_seminar_20100524_TG* and *MOSEM_WP5_DigitalGuideOfDigitalMeans_20100126_WP*	Focusing on MOSEM². it is impossible to add all previous trainings. Self study is basic and necessary
Invitation for teacher seminar	- teachers should do self study - teachers should bring their curriculum		Communicate MOSEM project family forum, website and repository	
For the teacher trainer	Understand the structure of the TS	- the TS consists of materials for the teacher trainers (study this in advance!), Materials for the participants and a series of Integrated activities for teachers. These are meant for the teachers, but, if they consider this usable for their students, it can be used for students too, provided some changes are made All activities are based on Coach PS: the Simulation activities can be transferred to another format, using Word and Excel for example.	WP5 Teacher Seminar Materials for participants Materials for trainers MO2_IntegratedActivities_WP MO_000_Start MO_221_MovingMagnetinCoil Models Simulations MO_223_falling_magnet_trough_coil Data_Ac&Video Help Models Simulations MO_337_Ski jumping in a magnetic field Coach Activities_337_Ski jumping	

Teacher seminar P1		**The first part of Teacher seminar 1 is the same for both the Activity and process types: the participants need to determine which group they belong to/with which profile they want to participate.**		
10	Introduction - project fact sheet - connection to previous projects	- short presentation	-PowerPoint on the project family: *MO2_project_family_20110104_VE_WP*	
50	Professionalizing teachers: determination of type of seminar: type A or type B - make teachers aware that LLL is needed and how this leads to quality education - also that there are quality standards that apply to them - let them learn what priorities this quality thinking sets for teachers - split all teachers in two groups	- teachers should fill out EFQM questionnaire - give the correct answers - self assessment, given the answers: a teacher can summarize his sheet and determine for himself to what category number he wishes to belong - characteristics of all 5 levels of EFQM are given: it is stressed that all people only need to look to the next category to improve. Only improvement counts, not the status itself. Bottom line is: choose between Activity profile or Process profile	- questionnaire: *MO2_WP5_Teacher_Seminar_profile_teachers_quest_20100118Nott_WP* - overview of categories *MO2_WP5_What_is_EFQM_PONTOn_20110104_WP* - basic ideas behind EFQM (also look at *MOSEM_PCK teacher_SIF09_20091230_MM* and *Rapinen_quality of education*	- the teacher seminar will have two learning paths: one for Activity based learners, one for process based learners - the former need very much help MOSEM_WP5_Teacher_Seminar_profile_teachers_quest_20100116Nott_WP For this group, this background information is crucial
30	Global information: resources available; organisation	Show crucial guides, files and other means to get access to resources	*MO_all_deliverables_overview_teacher_seminar_20100524_TG* and *MOSEM_WP5_DigitalGuideOf DigitalMeans_20100126_WP* Websites and repository	This group needs to know what is available: it is necessary to stress this topic.
Pause				
60	Group forming + first exploration of techniques and materials; the groups can determine who is going to what (spreading of tasks), based on the tree of materials available (see overview)	Learn about the Coach environment Learn about the EJS environment Learn about data acquisition Learn about data video	Hint: Activities in folder *MO_000_Start* , start with MO2_000_start The teacher asks for the task lists and the duration needed for this exploration (max. 60 min) The groups should indicate what to do if people are ready earlier	

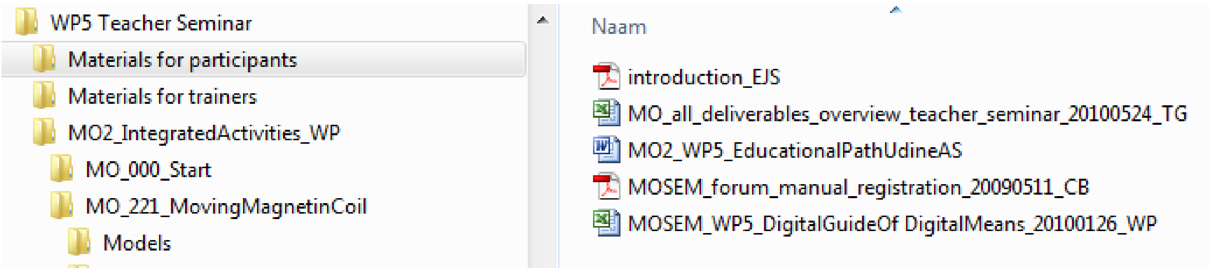
30	Learn about the SUPERCOMET 2 online animations, slide 4 and 5 Learn how to work with simulations If a reasonable series is done it will be OK; it is NOT possible to do it all	*0_MO2_221_MagnetHorCoil_start* *1_MO2_221_Online* in folder *MO_221_MovingMagnetinCoil* *Start with 221S_MagnetHorCoil_intro,* then *221S_MagnetHorCoil_process*	All materials are available.	For Activity oriented people the order is set. Everything is prepared, including tables etc. What skills are needed? - to have a minimum experience in working with Coach - or to be able to set up a table of datasets, with initial choices of independent parameter - to be able to analyze a set of data via the table and/or the diagram - to be able to formulate a conclusion
10	Discussion between participants	First impressions	The teacher trainer gathers the most important ideas regarding the format of the teacher seminar and the content of the materials.	

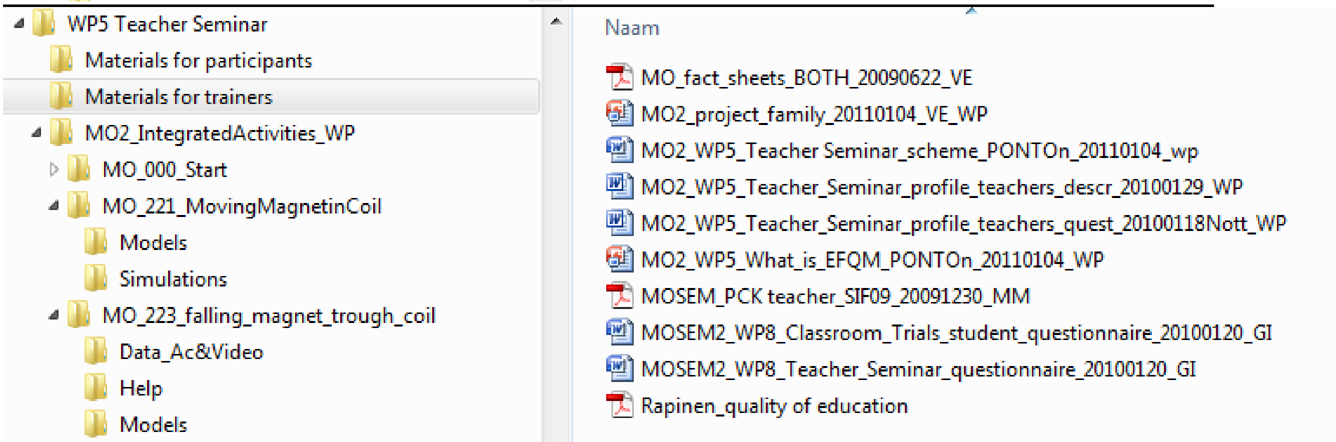
Teacher seminar P2			
10	Introduction: what did we learn last time	Discussion between participants	**This series is of course not really worked out, but the draft, the scheme of the lessons, including the goals of them, should be clear. This scheme can be presented on a flip chart for example.** **Task given by the teacher trainer: "At the end of this session every group presents a typical series of lessons on a topic that is related to the curriculum"**
120 minutes: groups decide pauses	Models, simulations, data acquisition, data video: learn materials, techniques and resources		221M. Electromagnetic induction by a moving magnet A with animation 221M. Electromagnetic induction by a moving magnet A 221M. Electromagnetic induction by a moving magnet B with animation 221M. Electromagnetic induction by a moving magnet B MO2_221M_Magnetization of a permanent magnet_20100120_PU MO2_221M_v1_Electromagnetic induction by a moving magnet_NonElab_

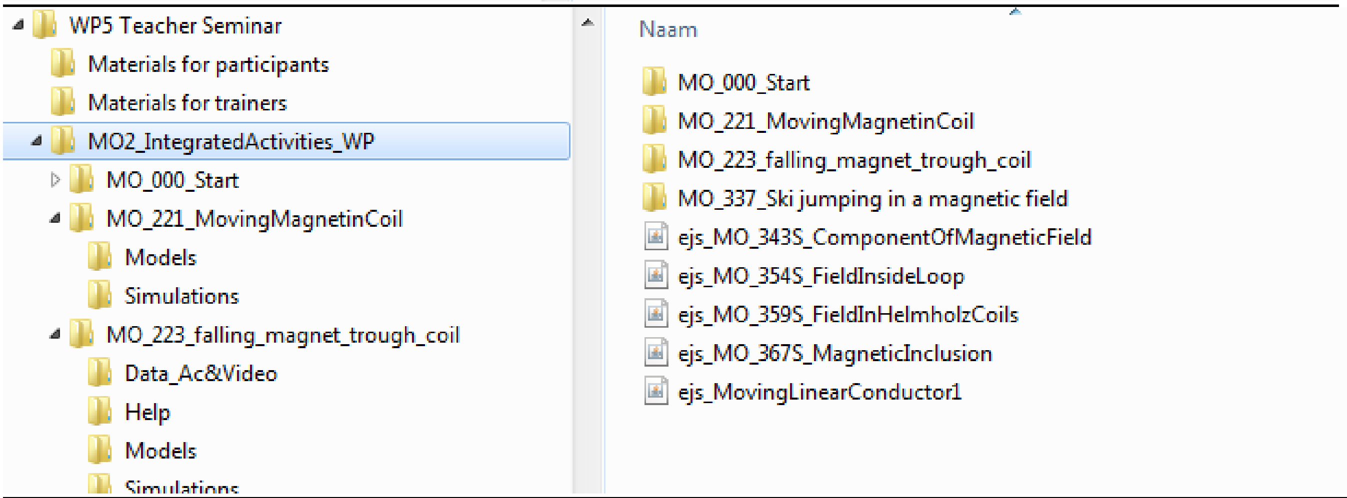
	Full integration of activities: data acquisition, simulations, modeling, data video The materials given on the right are available. The groups decide what they take or not; apart from that it is possible that other materials (from the website or repository or a real experiment with certain observations will be needed)	Look in Folder MO_223_falling_magnet_through coil Focus on the files that start with 3a, 5 and 6b, all others are not meant for this group. Of course it is possible for them to have a look at it, as it can be a part of their learning process.		
	Look in the folder and carry out *MO2_223D_ Electromagnetic induction by a falling magnet*			
	Look in the folder "Models" and study the models given			
	Look in the folder "MO_337_Ski jumping in a magnetic field" and then in the folder "Coach Activities_337_Ski jumping".			
30	Presentations of lesson schemes by the different groups		Flip charts	Discussion among the groups on the presentations
20	Evaluation by the teachers	Look in the folder "Materials for teachers", the file *MOSEM²_WP8_Teacher_Seminar_questionnaire_20100120_GI*		Please send the results of this evaluation both to Wim Peeters and Gren Ireson. Thank you!

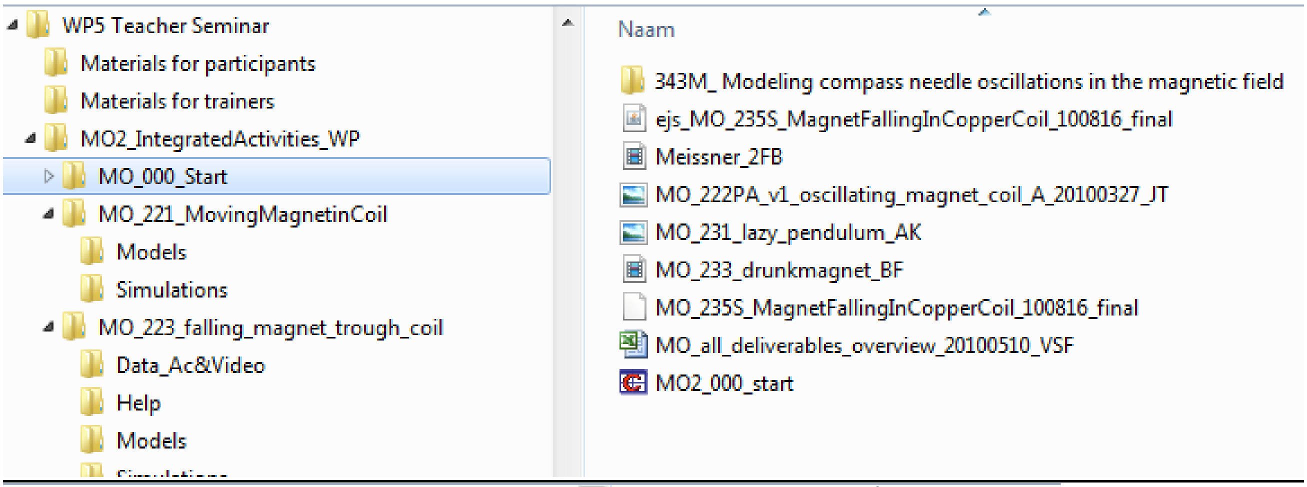
Teacher seminar P3		This seminar takes place about 1 year after the previous one		
180	Presentations of lesson schemes by the different participants of the Teacher seminars 1 & 2	Exchange of materials via the forum or other means The participants indicate additional working points for their learning (things they want to learn extra): the trainer provides this to them	Worksheets, powerpoints, courses, …	Discussion among the groups on the presentations

Overview of electronic materials used in the Teacher Seminar





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MO_221_MovingMagnetinCoil
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Simulations
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Data_Ac&Video
Help
Models
Naam
343M_ Modeling compass needle oscillations in the magnetic field
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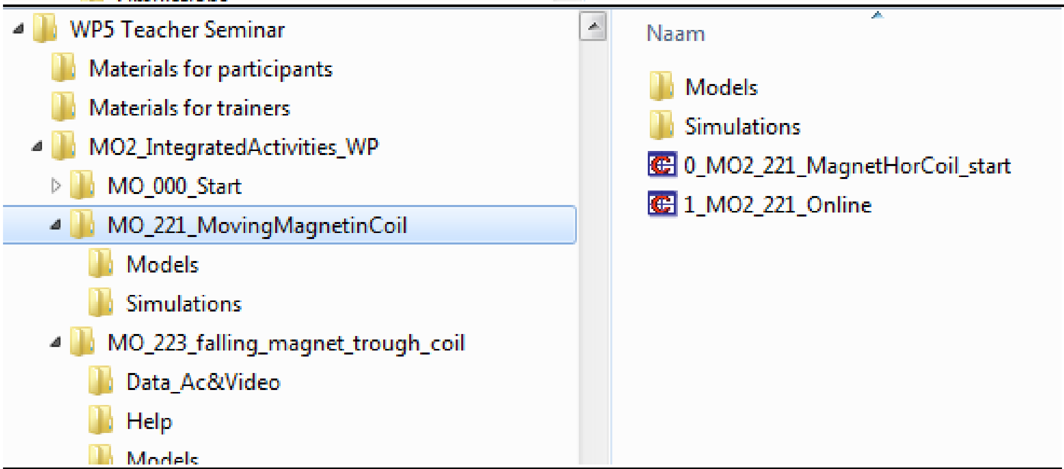
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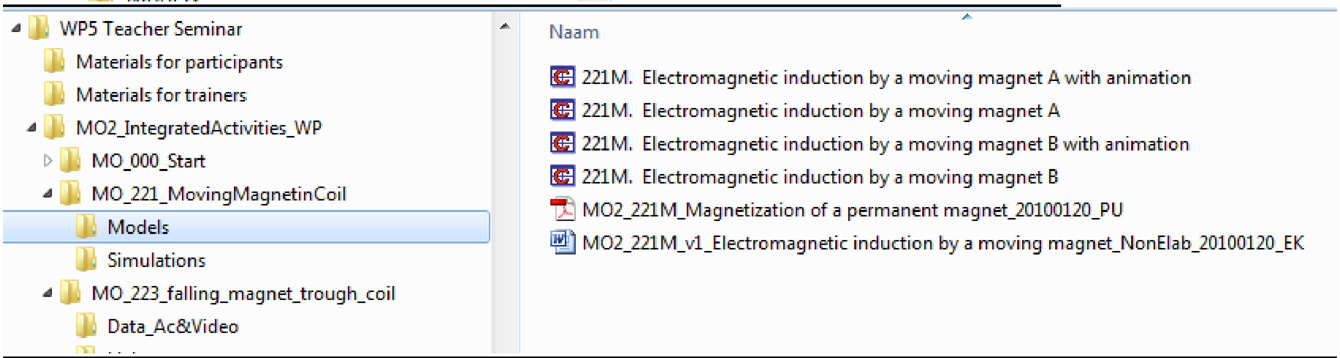
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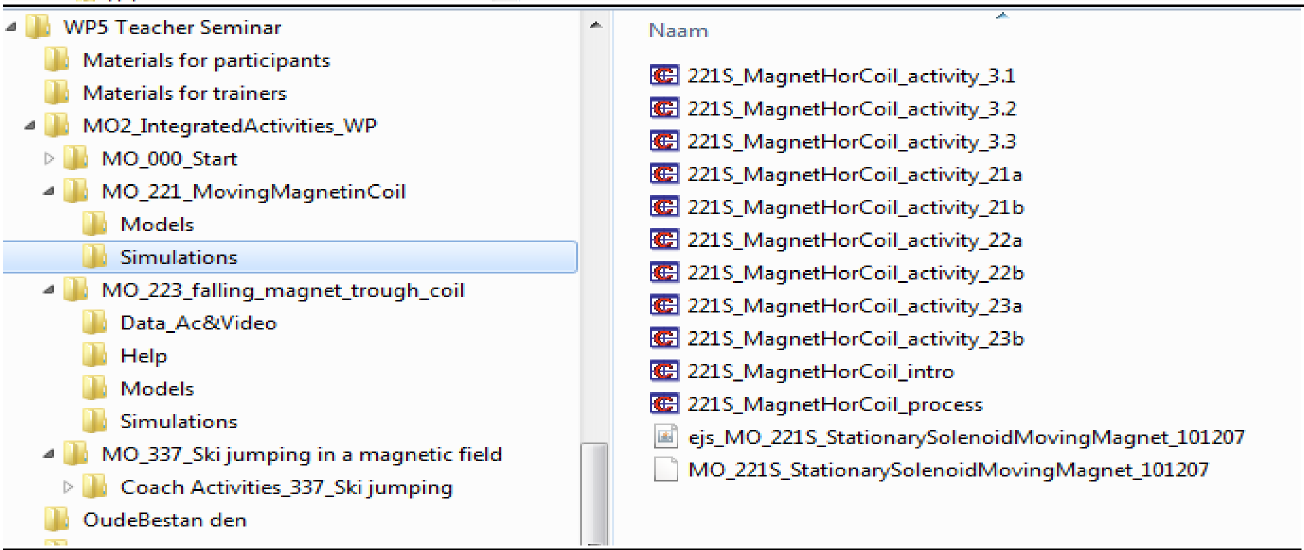
Naam
221M. Electromagnetic induction by a moving magnet A with animation
221M. Electromagnetic induction by a moving magnet A
221M. Electromagnetic induction by a moving magnet B with animation
221M. Electromagnetic induction by a moving magnet B
MO2_221M_Magnetization of a permanent magnet_20100120_PU
MO2_221M_v1_Electromagnetic induction by a moving magnet_NonElab_20100120_EK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Data_Ac&Video
Help
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Coach Activities_337_Ski jumping
OudeBestan den
Naam
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221S_MagnetHorCoil_activity_3.2
221S_MagnetHorCoil_activity_3.3
221S_MagnetHorCoil_activity_21a
221S_MagnetHorCoil_activity_21b
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221S_MagnetHorCoil_activity_22b
221S_MagnetHorCoil_activity_23a
221S_MagnetHorCoil_activity_23b
221S_MagnetHorCoil_intro
221S_MagnetHorCoil_process
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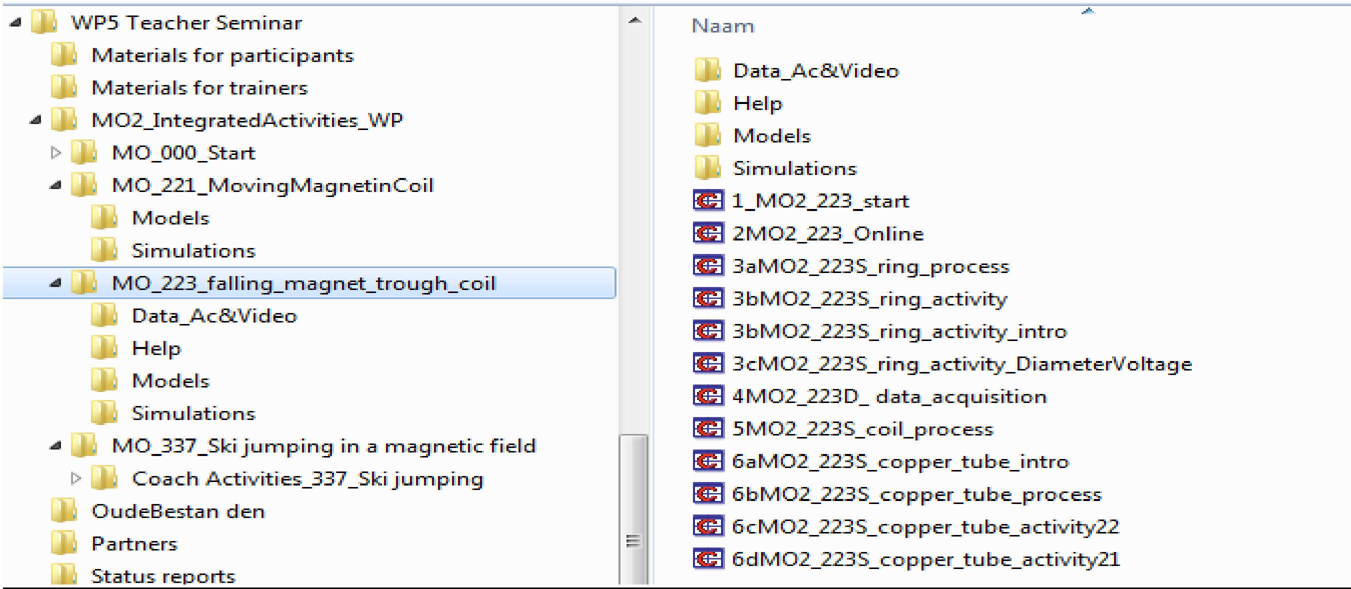
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Coach Activities_337_Ski jumping
OudeBestan den
Partners
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2MO2_223_Online
3aMO2_223S_ring_process
3bMO2_223S_ring_activity
3bMO2_223S_ring_activity_intro
3cMO2_223S_ring_activity_DiameterVoltage
4MO2_223D_ data_acquisition
5MO2_223S_coil_process
6aMO2_223S_copper_tube_intro
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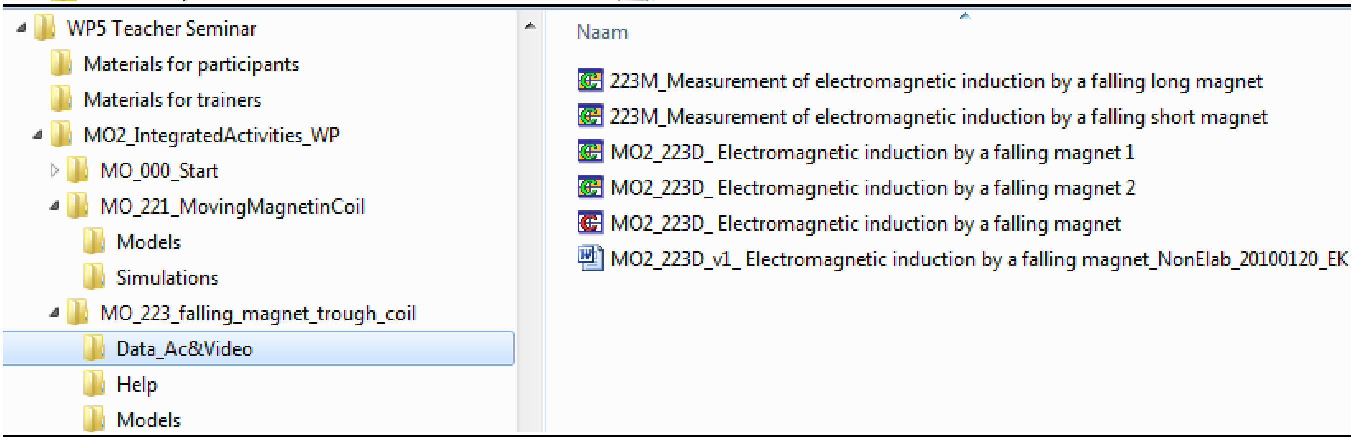
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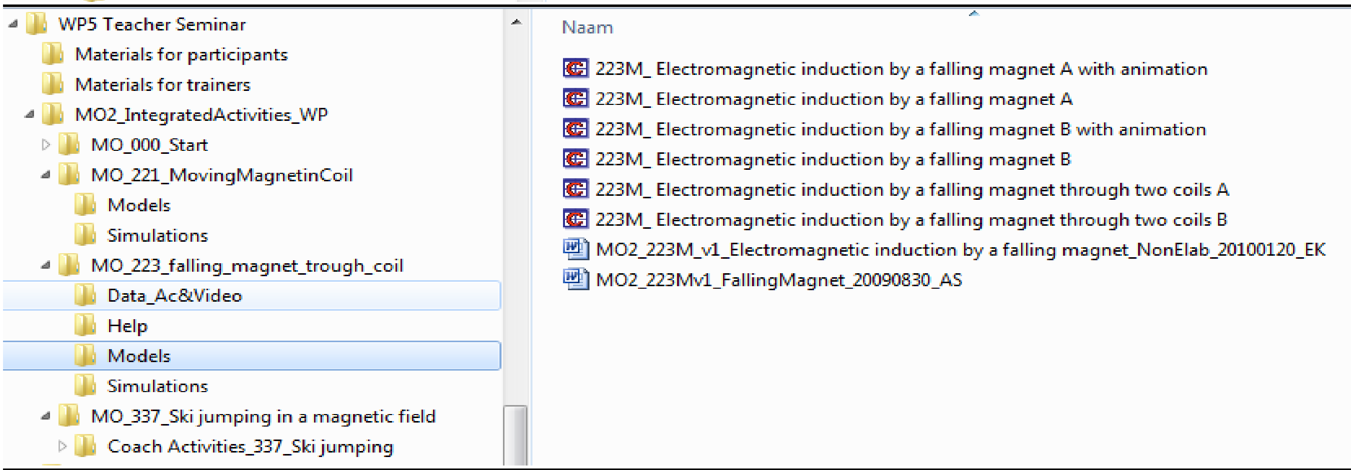
223M_Measurement of electromagnetic induction by a falling short magnet
MO2_223D_ Electromagnetic induction by a falling magnet 1
MO2_223D_ Electromagnetic induction by a falling magnet 2
MO2_223D_ Electromagnetic induction by a falling magnet
MO2_223D_v1_ Electromagnetic induction by a falling magnet_NonElab_20100120_EK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Coach Activities_337_Ski jumping
Naam
223M_ Electromagnetic induction by a falling magnet A with animation
223M_ Electromagnetic induction by a falling magnet A
223M_ Electromagnetic induction by a falling magnet B with animation
223M_ Electromagnetic induction by a falling magnet B
223M_ Electromagnetic induction by a falling magnet through two coils A
223M_ Electromagnetic induction by a falling magnet through two coils B
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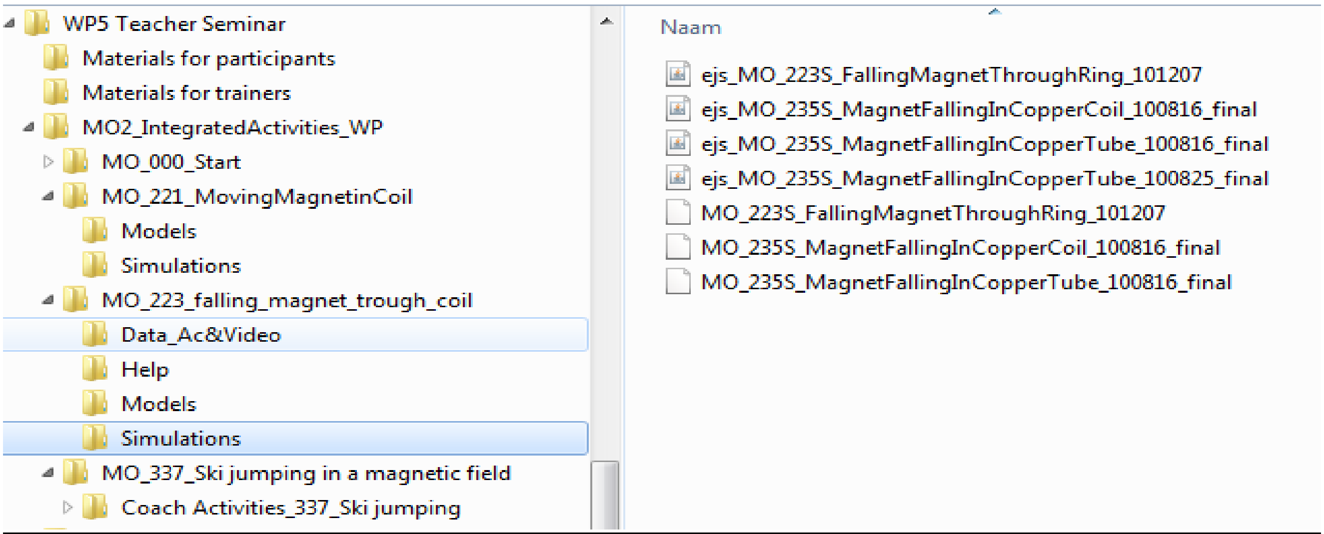
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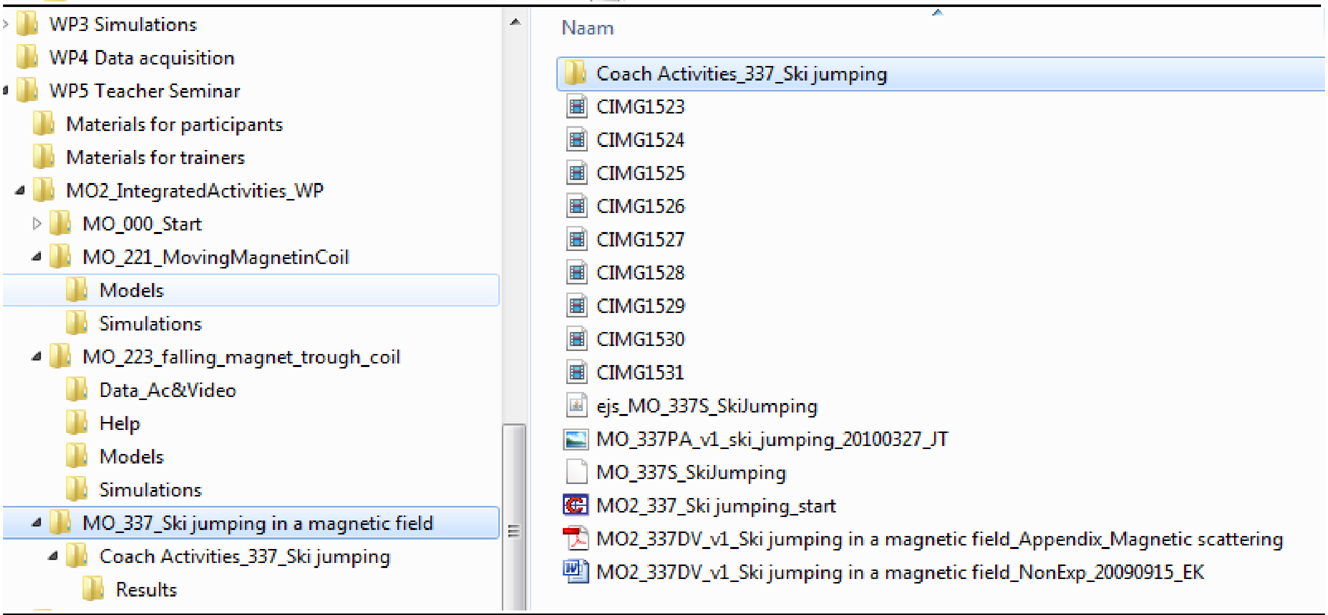
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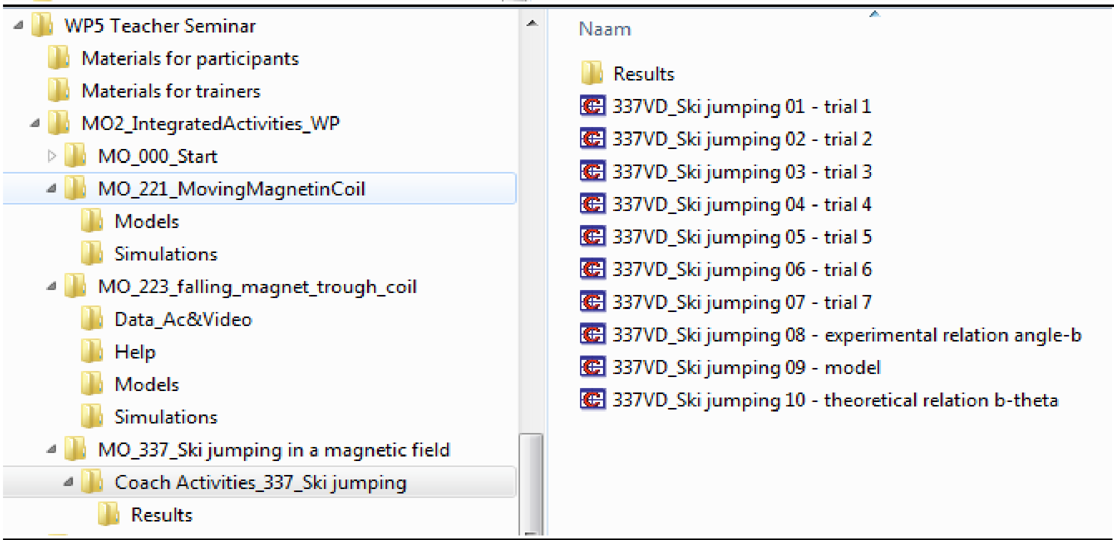
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Coach Activities_337_Ski jumping
Results
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Results
337VD_Ski jumping 01 - trial 1
337VD_Ski jumping 02 - trial 2
337VD_Ski jumping 03 - trial 3
337VD_Ski jumping 04 - trial 4
337VD_Ski jumping 05 - trial 5
337VD_Ski jumping 06 - trial 6
337VD_Ski jumping 07 - trial 7
337VD_Ski jumping 08 - experimental relation angle-b
337VD_Ski jumping 09 - model
337VD_Ski jumping 10 - theoretical relation b-theta

Activities

Introduction

In this section we present examples of different types of activities prepared to be used during Teacher Seminars and further in schools when teaching electromagnetism and superconductivity with Minds-On approach.

Each activity is numbered in a way introduced in the MOSEM project and associated with information linking the subject to on-line modules from SUPERCOMET and specific physics topic.

Integration

Integrating of different type of activities along with pointing benefits of each ICT tool plays main role in the Teacher Seminar. The chapter presents a few examples of MOSEM² modelling, simulation, data acquisition and animation activities for different related MOSEM experiments. It has to be mentioned that each presented experiment also has different types of associated activities – using different ICT tools. The whole integrated collection is available for downloading at mosem.eu.

Modelling

Experiment 1.2.4.M: R(T) for a Bulb

Chapter

1. Conduction

    1.2. Conduction and temperature

Link to other SC family files

Online learning modules: Module Conduction, Slide 32/35
Data acquisition: Experiment 1.2.4.D: R(T) for a Bulb

Learning objectives

- Using model to explore relation between resistance and temperature of a light bulb filament.
- Extending the given model by defining the resistance variable.

Applied ICT technology

Modelling

Experiment description

The model used in this activity enables the exploration of the relation between resistance (resistivity) and temperature of a filament (tungsten wire) like a one used in light bulbs.

As the resistivity of the bulb filament varies linearly with temperature, so does its resistance.

In equilibrium, the ingoing electric power equals the outgoing radiative power. This allows the student to determine the filament temperature for each particular voltage value.

The data generated via model can be then compared to data collected in an experiment in which a current-voltage characteristic of a light bulb is recorded (experiment 1.2.4.D. R-T bulb).
Such data are provided in the file '124M_I-U measured.cma'.

The physics of the experiment

The current I that passes through the bulb is given by Ohm's law: $I = \frac{U}{R}$

The resistance of the filament is given by: $R = \frac{\rho L}{S} = \frac{\rho L}{\frac{1}{4}\pi d^2}$

where L and d are the length and the diameter of the filament, respectively.

The resistivity of a metallic conductor nearly always increases with increasing temperature. The resistivity of a metal can be represented approximately by the linear equation:

$$\rho(T) = \rho_0[1 + \alpha(T - T_0)]$$

where ρ_0 is the resistivity at a reference temperature T_0 and α is the temperature coefficient of resistivity. The model assumes such linear dependence of the resistivity as a function of temperature.

Assuming equilibrium between the supplied electrical power and the outgoing radiative power obeying the Stefan-Boltzmann T^4 law (neglecting dissipation):
$P_{el} = P_{rad}$
$U \cdot I = A \cdot \sigma T^4$ where A is the effective radiating surface area

The effective radiating area is: $A = f \cdot \pi \cdot d \cdot L$
and the filament temperature can be determined for each given value of U and I:

$$T = \sqrt[4]{\frac{U \cdot I}{A \cdot \sigma}}$$

where:

- $\rho_{293} = 55x10^{-9}\Omega \cdot m$ resistivity of Tungsten at 20° C.
- $\alpha = 4.9x10^{-3}K^{-1}$ temperature dependence coefficient Tungsten
- $\sigma = 5.67x10^{-8}Wm^{-2}K^{-4}$ constant of Stefan-Boltzmann
- $L = 0.10m$ length of the filament
- $d = 5x10^{-5}m^{-5}$ diameter of the filament
- $f = 0.3$ effectively radiating fraction of the filament area

A is the effective radiating area $A = f \cdot \pi \cdot d \cdot L$ and $0 < f < 1$ is a fraction describing the effective radiating area and, to a lesser degree, the filament greyness.

In practice, $f \approx 0.3$ [1] but obviously independent temperature measurements are necessary to determine *f* more accurately.

Literature

Leff (1990) and Santi & Michelini (2006).

Minds-On questions

- What is the independent variable in this model?
- Construct the expression for the resistance as part of the model, given that R depends on ρ_{293}, α, T, L and d. Assume that:
  $\rho_{293} = 55x10^{-9}\Omega \cdot m$ resistivity of Tungsten at 20° C.
  $\alpha = 4.9x10^{-3}K^{-1}$ temperature dependence coefficient Tungsten
- Explain the definition of the power.
- Explain the definition of the temperature, including the condition, in detail: If P > 0.0021 W then $T = \sqrt[4]{\frac{U \cdot I}{A \cdot \sigma}} = \sqrt[4]{\frac{P}{f \cdot \pi \cdot d \cdot L}}$ else T=293.
- What is the relation between the resistance and the temperature of a filament?
- What is the relation between the resistivity and the temperature of a filament?
- Fit the resistivity versus temperature graph towards the processed results of measured data in order to obtain the best values of ρ_{293} and α by simulation. Use on the background graph the data of resistance and temperature provided in the file '124M_I-U measured.cma'.
- Vary both the length and the diameter of the filament in order to investigate what the optimal parameters are with the operating voltage of 6.0 V for a front and rear bicycle light.

Analysing student activities

Students get the model in which the resistance variable R is not defined. They are asked to construct the expression for the resistance, given that R depends on ρ_{293}, α, T, L and d.

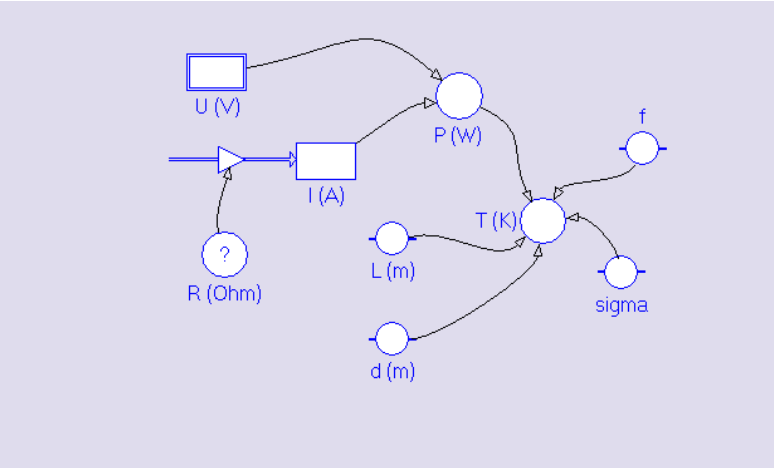


Figure 1. Model without defined R

The final model with defined resistance:

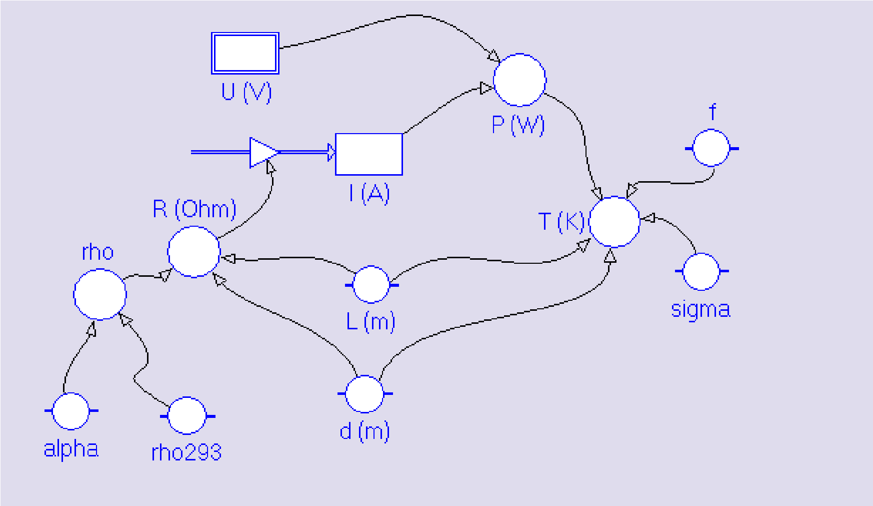
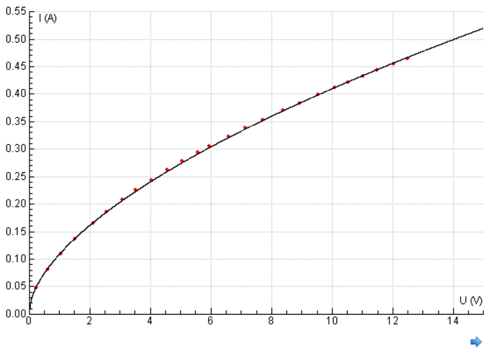
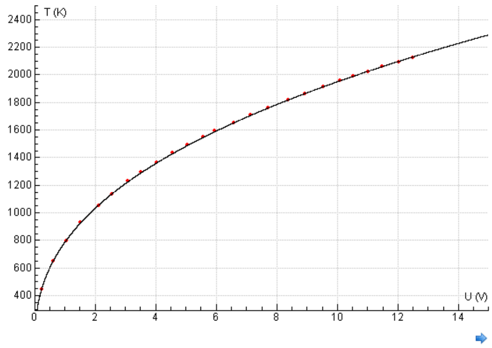


Figure 2. Model with defined R

Next the students have to explain the definition of the power and the temperature.

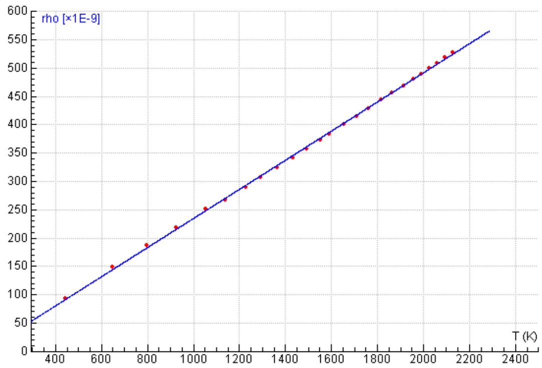
Calculated from the model, the computer displays both the characteristic of the bulb and the variation of temperature versus voltage.





More importantly, resistivity as a function of temperature is plotted in a diagram showing an obvious linear relation.

The processed data from an actual measurement are given (here shown in the form of a red-dotted background graph) to allow the student to optimize the model to the Tungsten data or any other metal for that matter (simulate different values of ρ_{293} and α).



As a more advanced assignment, the student may study and explain a model for the transient effect when switching on a lamp. This model is a bit more complicated, based on the assumption that the supplied electrical power is partly used to heat the filament and is partly lost by radiation. Convective effects are neglected.

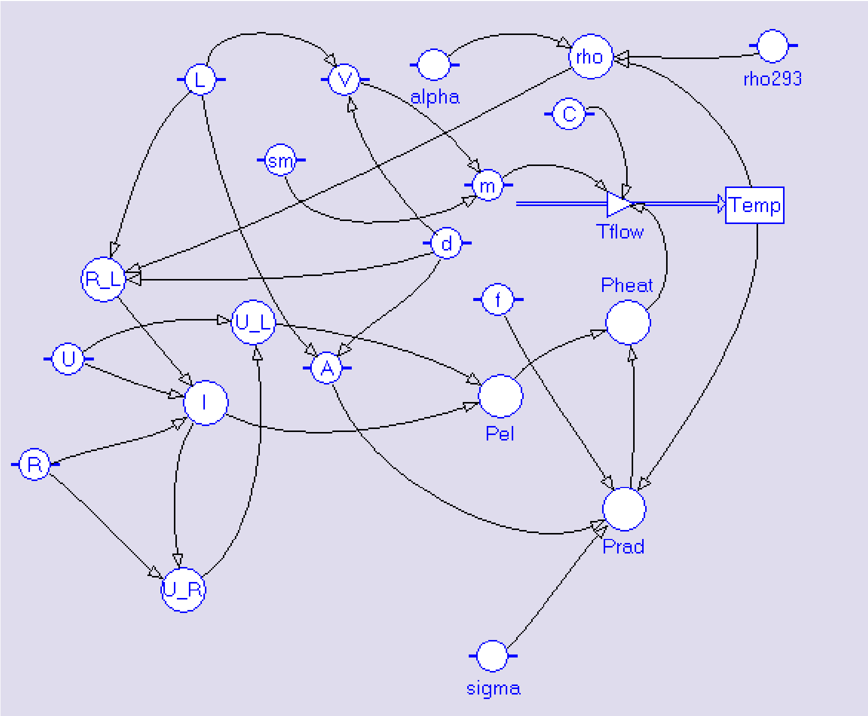


Figure 3. Model for transient effect

Available Coach Activities: 124M_R-T bulb 01.cma
124M_R-T bulb 02 - I-U measured.cma
(experimental data which can be used for comparison with model results)

Available Coach Results: 124M_R-T bulb 01.cmr
124M_R-T bulb 02 - Switched bulb.cmr

Experiment 2.1.3.M: Faraday Experiment

Chapter

2. Electromagnetic induction

    2.1. Induced EMF in a moving conductor

Link to other SC family files

Online learning modules: Module Induction, Slide 9/17
Animation: Activity 2.1.3.A Faraday Experiment

Learning objectives

- To become familiar with the concepts of changing magnetic flux, induced (motional) emf and current associated with Faraday’s Law of Induction.
- To determine how the velocity of the conductor bar moving in a uniform magnetic field changes in time.

Applied ICT technology
Modelling

Experiment description
In this activity student analyse the motion and induced EMF and current in a conductor moving in a uniform magnetic field. They start with a model which describes a situation when a conducting bar with initial velocity to the right slides along two conducting parallel rails, as shown in the figure.
A uniform magnetic field is applied vertically downward (pointing into page).

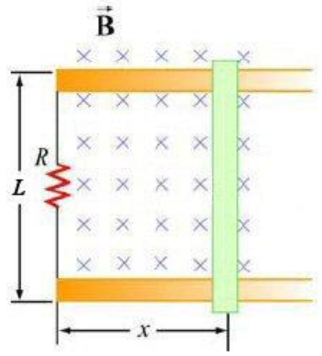


Figure 4. Conducting bar

Then students extend the model to be able to analyse the more complex problem: a car of mass m is pulled in the horizontal direction across two parallel rails by a massless string which passes over a pulley and is connected to a block of mass M, as shown in Figure. One of the car axles makes a conductive connection between the rails. The car is released from rest.

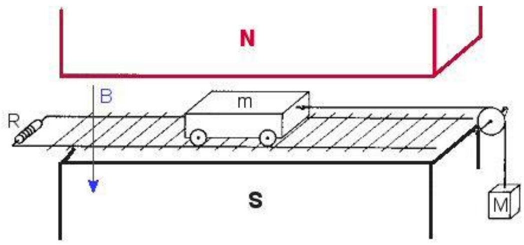


Figure 5. Conducting car

The physics of the experiment
The conducting bar slides along two frictionless conducting parallel rails which are connected together by a resistor with resistance R as shown in the figure at the right. The bar moves through a region of uniform magnetic field B which is directed into the page. The bar has mass m, length L and gets initial velocity v to the right. As the bar slides to the right a counter clockwise current is induced in the circuit consisting of the bar, rails and the resistor.

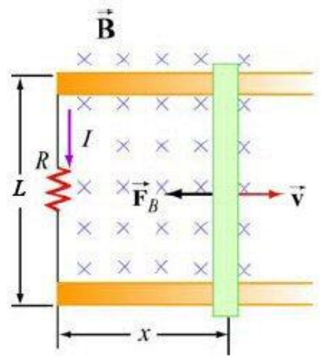


Figure 6. Moving bar

The conductor bar moves to the right with an initial velocity v. The magnetic flux through the closed loop formed by the bar and the rails is given by:

$$\Phi_B = BA = BLx$$

Moving the bar to the right increases the area of loop, increasing the flux. According to Faraday's law, the induced (motional) emf is:

$$\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d}{dt}(BLx) = -BL\frac{dx}{dt} = -BLv$$

where $\frac{dx}{dt} = v$ is simply the speed of the bar.

The corresponding induced current is $I = \frac{\varepsilon}{R} = \frac{BLv}{R}$.

According to Lenz's law its direction is counter-clockwise (upward in the bar).

Because it's in a magnetic field, the bar experiences a force because of the interaction between the field and the current $\vec{F}_B = -I\vec{L}x\vec{B}$.

Since the magnetic field B is perpendicular to the bar

$$F_B = -ILB = -\frac{B^2L^2v}{R}$$

This force always acts to oppose the motion of the bar. Because this force is the only force acting on the bar, Newton's second law applied to the motion in the horizontal direction gives

$$F = Ma = -\frac{B^2L^2}{R}v$$

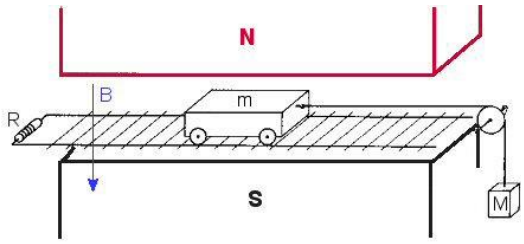


Figure 7. Car pulled by mass M

The analytical solution of this equation is $v(t) = v_0 e^{-t/\tau}$ where $\tau = \frac{MR}{B^2L^2}$.

Extension of the model – a car pulled by mass

Now a car of a mass M is pulled in the horizontal direction across two frictionless parallel rails at a distance L apart by a massless string which passes over a frictionless pulley and is connected to a block of mass m. A uniform magnetic field is applied vertically downward. The car is released from rest.

This situation is similar to the previous one additionally there is a force which pulls the car to the right. Now we have two forces acting on the car, Newton's second law gives:

$$F = F_P + F_B = (m+M)a = Mg - \frac{B^2L^2}{R}v$$

After some time the resultant force F becomes zero and the car moves with constant velocity.

Minds-On questions

- Explain why there is a current inducted in the bar and in which direction it flows?
- Analyse the given model and explain the definition of magnetic force F_B.
- Explain the definition of the induced EMF and corresponding induced current?
- Based on your model graphs explain the graph of induced EMF and induced current.
  All graphs are available via the yellow Diagram button.
- Find the velocity of the bar as a function of time and describe the motion of the bar.
- Determine how the force is changing in time?
- What will happen when the magnitude of the magnetic field is larger?
- What will happen when the direction of the magnetic field changes, pointing out of the page?

- What will happen when the conducting bar is given an initial velocity to the left instead of to the right?
- Do you have an idea how to keep the bar moving with constant speed?

For a model of a car pulled by a mass:

- What are the forces acting on the moving car?
- What is the total force acting on the moving car?
- What is the car's acceleration?
- Find the velocity of the car as a function of time and describe its motion.
- What is the terminal speed of the car?

Analysing student activities

Students start with the given model of the conducting bar sliding on the rails in the magnetic field. They analyse the model and definitions of the magnetic force F_B, induced EMF and corresponding induced current?

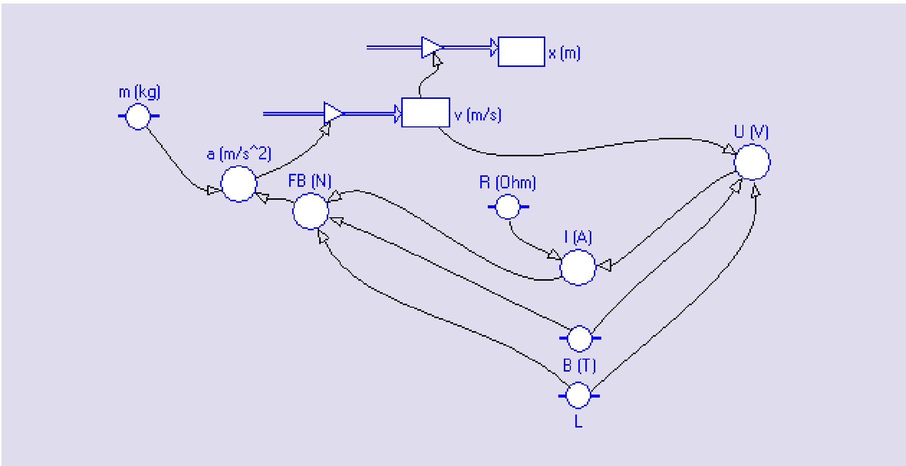


Figure 8. Model of conducting bar sliding on rails

They have to find the speed of the bar as a function of time and describe the motion of the bar. Below, example data of induced EMF and current in the moving bar as a function of time.

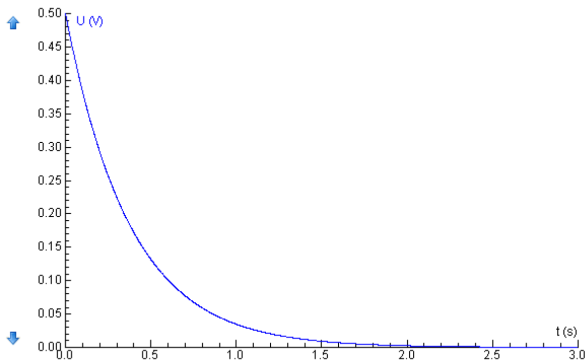


Figure 9. Induced EMF vs. time

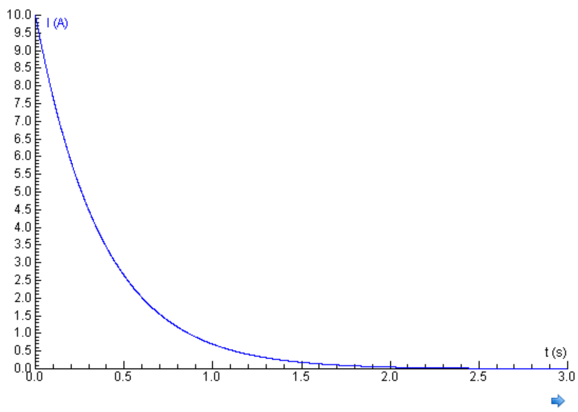


Figure 10. Induced current vs. time

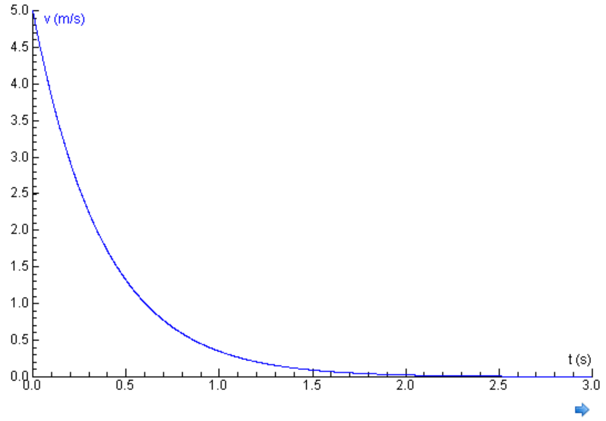


Figure 11. Velocity vs. time

Then students have to extend the model by:

- adding and defining the force responsible for pulling the car,
- adding and defining the total force, and
- modifying the expression for the acceleration.

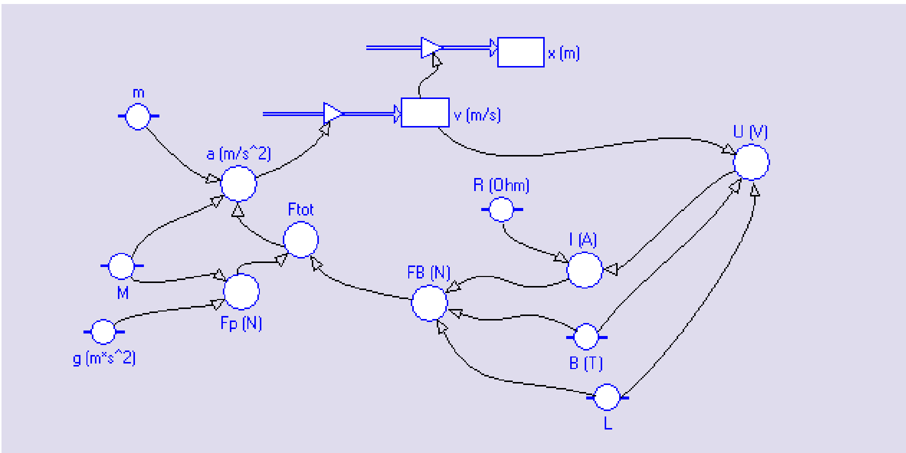


Figure 12. Model of accelerating car

After some time the total force acting on the moving car becomes zero and the car reaches its terminal speed.

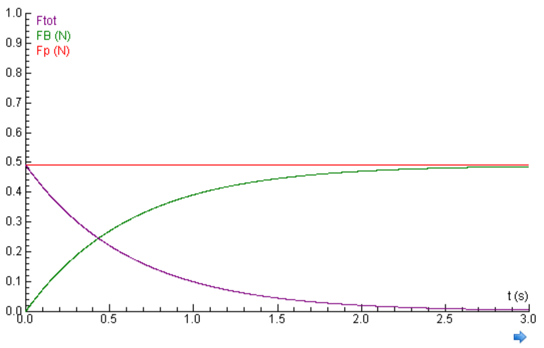


Figure 13. Force vs. time

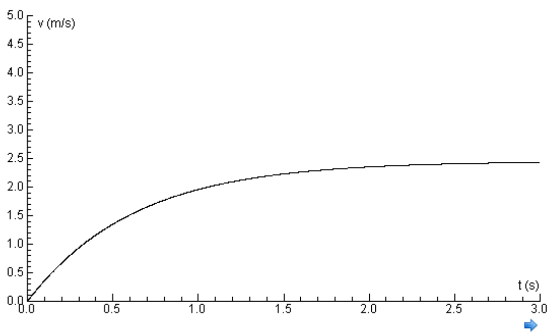


Figure 14. Velocity vs. time

Available Coach Activities: 213M_Induced EMF in a moving conductor 01.cma
Available Coach Results: 213M_Induced EMF in a moving conductor 01.cmr
213M_Induced EMF in a moving conductor 02 - car pulled by a mass.cmr

Experiment 2.2.1.M: Induction by a Moving Magnet

Chapter

2. Electromagnetic induction

    2.2. Moving magnet

Link to other SC family files

Online learning modules: Module Induction, Slide 4/5

Learning objectives

- To become familiar with the concepts of changing magnetic flux and induced electromotive force emf associated with Faraday's Law of Induction.
- To investigate, by using model simulations, how the induced emf is affected by different parameters like: radius of the coil, number of coil loops, velocity of the magnet and magnetic dipole moment.

Applied ICT technology

Modelling

Experiment setup

In this activity students investigate, by using a given model, a phenomenon of electromagnetic induction which is caused by a moving with constant velocity magnet. As the magnet moves along the axis of the coil the magnetic flux through the coil changes and an electromotive force appears at the coil ends.

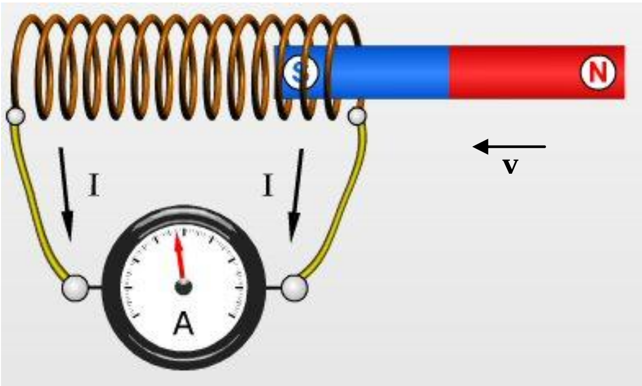


Figure 15. Moving magnet

The physics of the experiment

When a magnet is moved into and out of a coil of wire, current is induced in the wire. This phenomenon is called electromagnetic induction.

According to Faraday's law, the induced electromotive force emf ε is proportional to the negative of the rate of change of magnetic flux Φ

$$\varepsilon = -\frac{d\Phi}{dt}$$

The direction of the induced current is determined by Lenz's law, the induced current produces magnetic field which tends to oppose the change in magnetic flux that induces such currents.

For a coil that consists of N loops, the total induced emf would be N times as large:

$$\varepsilon = -N\frac{d\Phi}{dt}$$

Assuming that the magnet moves in the horizontal direction x with constant velocity v and crosses the coil through its centre the equation can be re-written in the following form:

$$\varepsilon = -N\frac{d\Phi}{dt} = -N\frac{d\Phi}{dx} * \frac{dx}{dt} = -Nv\frac{d\Phi}{dx} \quad (1)$$

Where the magnetic flux Φ_B through an area A is defined as $\Phi = \int \vec{B} \bullet d\vec{A}$.

In literature different approaches to estimate the magnetic field B of a permanent magnet and the change of magnetic flux can be found [1], [2], [3].

A simple approximation, which can be used for a magnet which size is relative small compare to the coil, is a point magnetic dipole approximation. The detailed description of this approach can be found in the paper *Magnetization of a permanent magnet*. For this approximation

$$\frac{d\Phi}{dx} = -\frac{3}{2}a^2\mu_0\mu\frac{x}{(x^2+a^2)^{5/2}} \quad (2)$$

where *a* is the radius of the coil and *μ* is the magnetic dipole moment of the magnet.

A more realistic approximation assumes that the magnet has length l=2L is approximation of stacked magnetic dipoles. The detailed description of this approach can also be found in the paper *Magnetization of a permanent magnet*. For this approximation

$$\frac{d\Phi}{dx} = a^2\frac{\mu_0\mu}{4L}\left(\frac{1}{((L+x)^2+a^2))^{3/2}} - \frac{1}{((L-x)^2+a^2))^{3/2}}\right) \quad (3)$$

Literature

Fredrickson & Moreland (1972), Kingman et.al (2002) and Manzanares (1994).

Uylings (2010), *Magnetization of a permanent magnet*, which can be downloaded from mosem.eu.

Minds-On questions

- Predict (sketch) a graph of the induced EMF as a function of time.
- Execute your model, why are there two peaks of opposite sign?
- The areas under the two segments of the curve are the same. Explain why this is so.
- How does changing the coil radius *a* influence the induced EMF?
- How does changing the number of coil loops *N* influence the induced EMF?
- How does changing the magnet velocity *v* influence the induced EMF?
- How does changing the magnetic moment *μ* of the magnet influence the induced EMF? What does it mean to change the magnetic moment μ?
- How is the induced EMF affected by reversing a magnet? How could you simulate this?

Analysing student activities

Students work with a given model, they analyse it and use it to simulate different situations.

In the model is assumed that the south pole of the magnet enters the coil first. The position x of a moving magnet can be found by equation:

$$\frac{dx}{dt} = v \text{ where v is constant.}$$

There are two models available; the difference between them is the way of describing $\frac{d\Phi}{dx}$.

Model A

This model is based on the approximation of a point magnetic dipole, $\frac{d\Phi}{dx}$ is described by the equation 2.

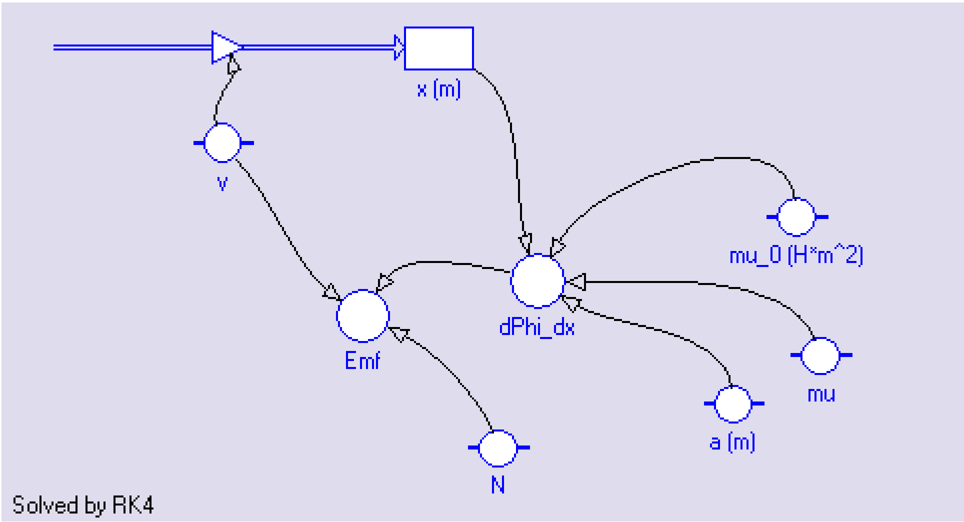


Figure 16. Model A

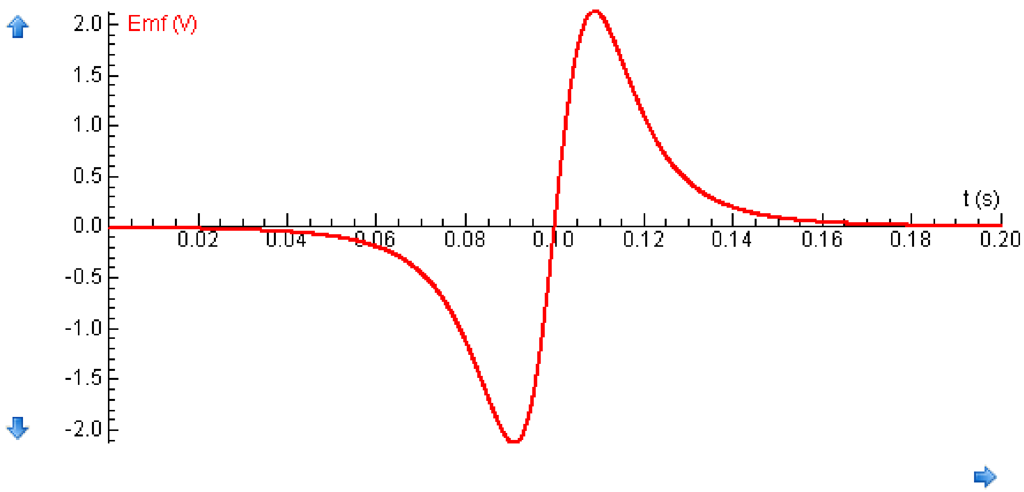


Figure 17. Resulting induced emf characteristic, model A

Model B

This model is based on the approximation of a point magnetic dipole, $\frac{d\Phi}{dx}$ is described by the equation 3.

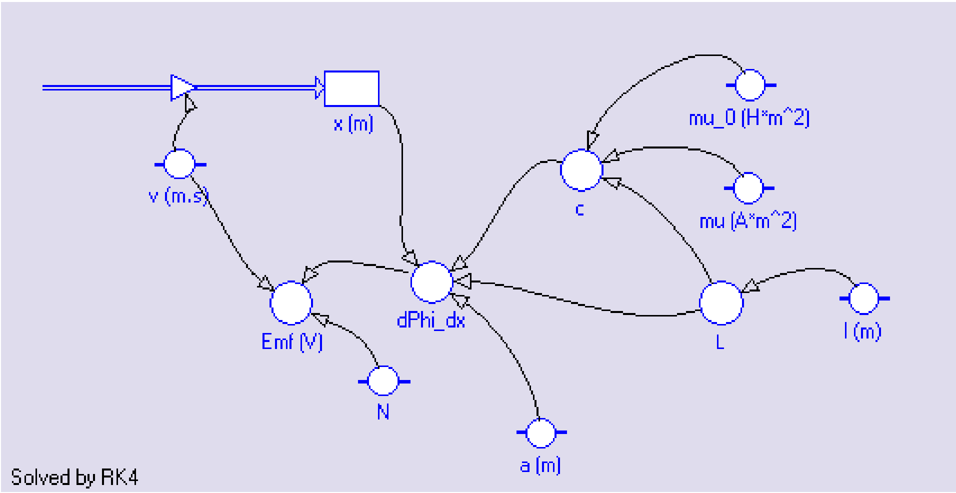


Figure 18. Model B

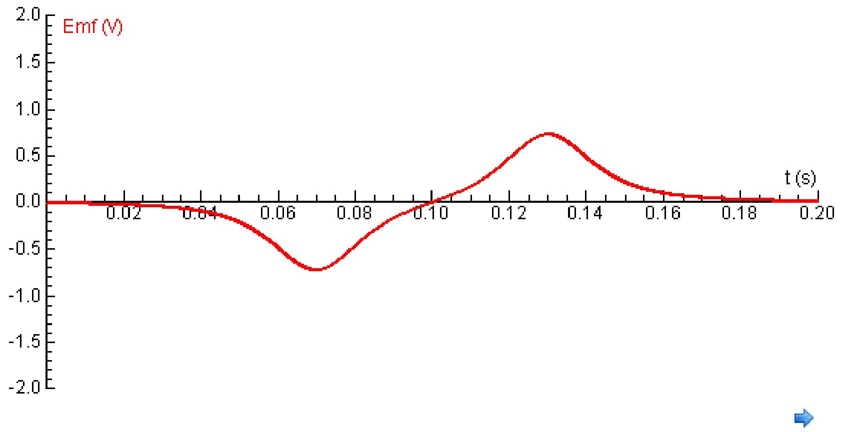


Figure 19. Resulting induced EMF characteristic, model B

The resulting induced EMF characteristic (with similar parameters as used in Model A). There are two additional Activities A and B which are enriched with animations that visualizes the magnet motion.

Figure 20. Induced EMF from moving magnet

Available Coach Activities: 221M_ Induction by a moving magnet A.cma
221M_ Induction by a moving magnet A with animation.cma
221M_ Induction by a moving magnet B.cma
221M_ Induction by a moving magnet B with animation.cma

Experiment 2.2.3.M: Electromagnetic Induction by a Falling Magnet

Chapter

2. Electromagnetic induction
    2.2. Moving magnet

Link to other SC family files

Online learning modules: Module Induction, Slide 20
Data acquisition: Experiment 2.2.3.D Electromagnetic Induction by a Falling Magnet

Learning objectives

- To become familiar with the concepts of changing magnetic flux and induced electromotive force emf due to a falling magnet motion
- To investigate, by using model simulations, how the induced emf is affected by different parameters like: radius of the coil, number of coil loops, velocity of the magnet and magnetic dipole moment
- To compare experimental results with model predictions

Applied ICT technology

Modelling

Experiment setup

In this activity students investigate, by using a given model, a phenomenon of electromagnetic induction which is caused by a magnet falling through a coil.
As the magnet falls the magnetic flux through the coil changes and an electromotive force appears at the coil ends.

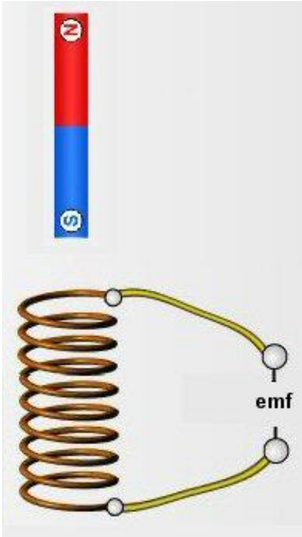


Figure 21. Falling magnet

The physics of the experiment

When a magnet falls through a coil of wire, current is induced in the wire. According to Faraday's law, the induced emf ε is proportional to the negative of the rate of change of magnetic flux Φ

$$\varepsilon = -\frac{d\Phi}{dt}$$

The direction of the induced current is determined by Lenz's law, the induced current produces magnetic field which tends to oppose the change in magnetic flux that induces such currents.
For a coil that consists of N loops, the total induced emf would be N times as large:

$$\varepsilon = -N\frac{d\Phi}{dt}$$

The magnet is released from rest at height h and falls freely under gravity acceleration g. Assuming that the magnet falls in the horizontal direction y along the central axis of the coil and has velocity v the equation can be re-written in the following form:

$$\varepsilon = -N\frac{d\Phi}{dt} = -N\frac{d\Phi}{dy} * \frac{dy}{dt} = -Nv\frac{d\Phi}{dy} \quad (1)$$

Where the magnetic flux Φ_B through an area A is defined as $\Phi = \int \vec{B} \bullet d\vec{A}$.

To estimate the magnetic field B of the magnet and to determine the change of magnetic flux similar approach as in experiment *2.2.1.M. Electromagnetic induction by a moving magnet* is used. Two approximations can be used for describing the change of magnetic flux.

A point magnetic dipole approximation, which can be used for a magnet which size is relative small compare to the coil (detailed described in Appendix *Magnetization of a permanent magnet*, chapter 3):

$$\frac{d\Phi}{dy} = -\frac{3}{2}a^2\mu_0\mu\frac{y}{(y^2 + a^2)^{5/2}} \quad (2)$$

where a is the radius of the coil and μ is the magnetic dipole of the magnet.

A stacked dipoles approximation, for longer magnets with length l=2L (detailed described in Appendix *Magnetization of a permanent magnet*, chapter 4.1):

$$\frac{d\Phi}{dy} = a^2\frac{\mu_0\mu}{4L}\left(\frac{1}{((L+y)^2 + a^2))^{3/2}} - \frac{1}{((L-y)^2 + a^2))^{3/2}}\right) \quad (3)$$

Literature

Fredrickson & Moreland (1972), Kingman et.al (2002) and Manzanares (1994).
Uylings (2010), *Magnetization of a permanent magnet*, which can be downloaded from mosem.eu.

Minds-On questions

- Predict (sketch) a graph of the induced emf as a function of time.
- Execute your model, why are there two peaks of opposite sign?
- Are the induction peaks symmetric? Compare the values of the minimum and maximum peaks.
- The areas under the two segments of the curve are the same. Explain why this is so.
- Explain the change in the induced emf as the dropping height of the magnet is increased.
- How a change of the coil radius a influences the induced emf?
- How a change of the number of coil loops N influences the induced emf?

- How a change of the magnetic moment μ of the magnet influences the induced emf? What does it mean to change the magnetic moment μ?
- How the induced emf is affected by reversing a magnet? How could you simulate this?
- Compare the experimental recorded data with the model results. Which model A or B come closer to your experimental data.
- Predict the induced emf graph when a second coil is placed in a series, at the distance d below the first coil?
- Can you predict the induced emf graph when a more than two coils (3, 4 or 5) are placed in series below each other at the equal distances between each other?

Analysing student activities

Students work with a given model, they analyse it and use it to simulate different situations. In the model is assumed that the south pole of the magnet enters the coil first. The vertical position y and velocity v of a falling magnet can be found by motion equations:

$$\frac{dy}{dt} = v \text{ and } \frac{dv}{dt} = g \text{ where g is gravity acceleration.}$$

The initial position of the magnet is h and its initial velocity is 0.

There are two models available; the difference between them is the way of describing the magnetic flux change $\frac{d\Phi}{dy}$.

Model A:

This model is based on the approximation of a point magnetic dipole, $\frac{d\Phi}{dy}$ is described by the equation 2.

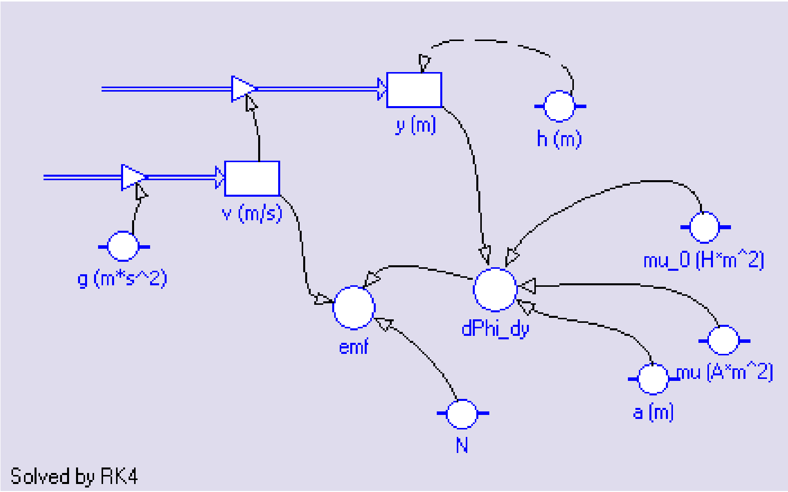


Figure 22. Model A

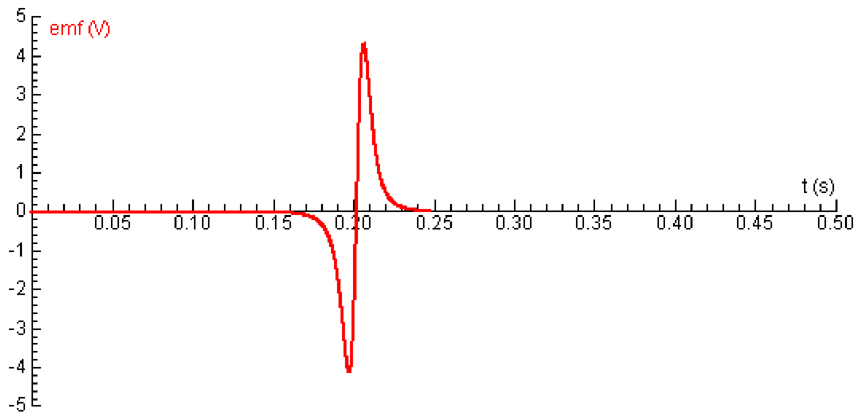


Figure 23. Resulting induced EMF graph, model A

Model B:

This model is based on the approximation of stacked dipoles, $\frac{d\Phi}{dy}$ is described by the equation 3.

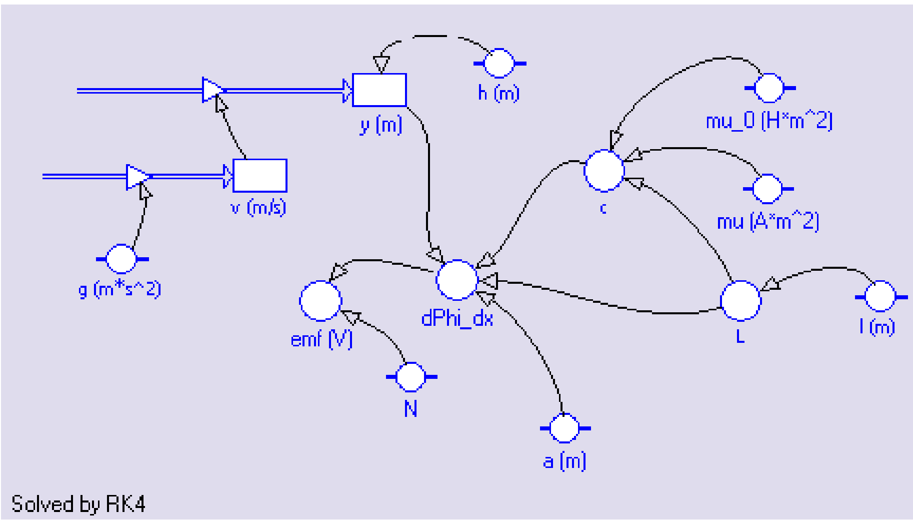


Figure 24. Model B

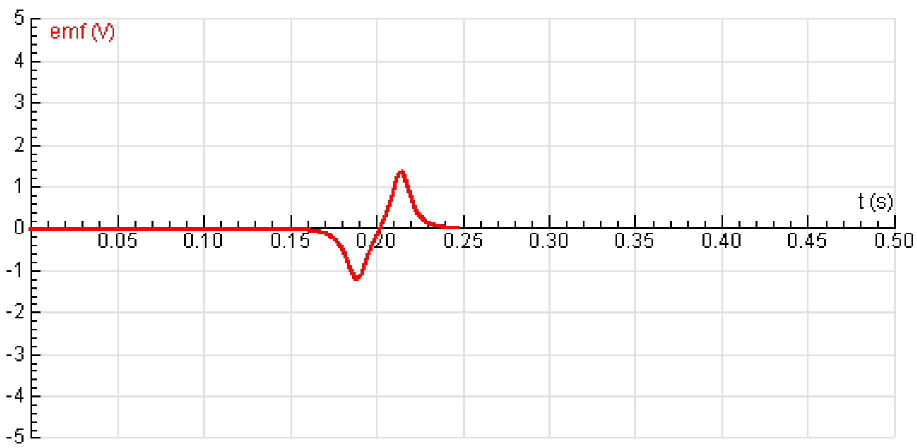


Figure 25. Resulting induced emf graph, model B

The resulting induced emf graph (with similar parameter values as used in Model A).

For comparison the experimental data from Coach Results can be used.

Two additional models are available for a system with two coils which are placed under each other, at a distance d. Similar to a single coil Model A is based on the approximation of a point magnetic dipole and Model B is based on the approximation of stacked dipoles.

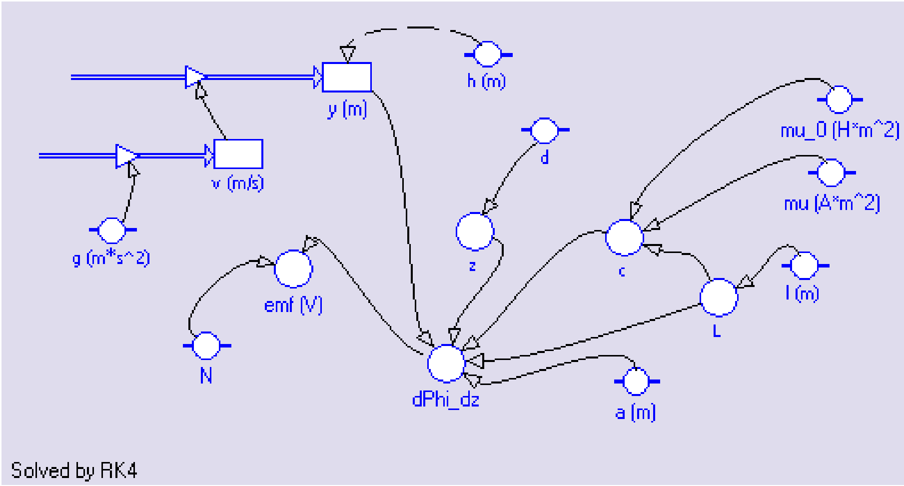


Figure 26. Model B

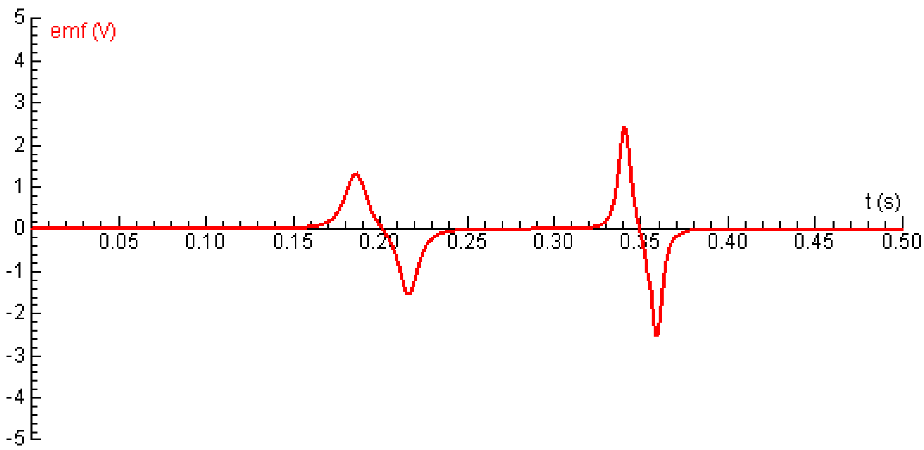


Figure 27. Resulting induced EMF graph

Available Coach Activities: 223M_Electromagnetic induction by a falling magnet A.cma
223M_Electromagnetic induction by a falling magnet B.cma
223M_ Electromagnetic induction by a falling magnet through two coils A.cma
223M_ Electromagnetic induction by a falling magnet through two coils B.cma

Available Coach Results: 223M_Measurement of electromagnetic induction by a falling long magnet.cmr
223M_Measurement of electromagnetic induction by a falling short magnet.cmr

The measurement results from these files can be used for comparison to model results.

Experiment 3.5.9.M: Field in Helmholtz Coils

Chapter
3. Magnetism
3.5. Magnetic effect of a current

Link to other SC family files
Online learning modules: Module Magnetism, Slide 29/30
Simulation: Experiment 3.5.9.S: Field in Helmholtz Coils

Learning objectives
- To analyze the magnetic field B generated by a pair of Helmholtz coil.
- To use the given model for simulations.

Applied ICT technology
Modelling

Experiment 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 d equal to the radius R of the coil. Each coil carries an equal electrical current flowing in the same direction.
The model given to students calculates and displays the magnetic field B generated by a pair of Helmholtz coils. Students use this model for simulations.

The physics of the experiment
According to the Biot - Savart law, the magnetic field at a point P on the axis of a circular current loop at a distance x from the centre is given by:

$B_x = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}}$ on the axis of a circular loop

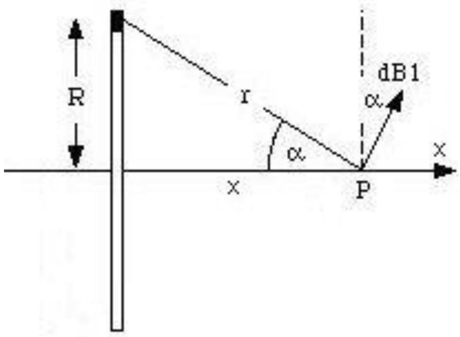


Figure 28. B-field at point P

Where:
- $\mu_0 = 4\pi \cdot 10^{-7}$ is magnetic permeability of the vacuum,
- I is the current carried in the coils,
- R is the radius of the coils, and
- $r = \sqrt{x^2 + R^2}$ is the distance between P and the current loop.

For coils with N loops: $B_x = \frac{\mu_0 N I R^2}{2(x^2 + R^2)^{3/2}}$

To find the magnetic field generated by a pair of Helmholtz coils, we assume that the coils are positioned at $x_1 = \frac{1}{2}d$ and $x_2 = \frac{1}{2}d$ of the x-axis,
so that the origin is at the centre of the two coils.

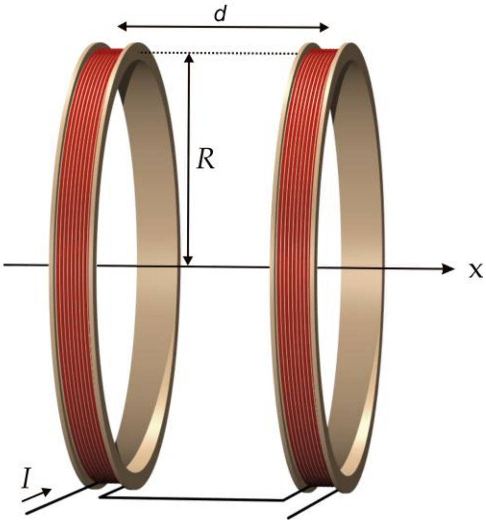


Figure 29. Helmholtz coils

The magnetic field generated by the first coil is:

$$B_1 = \frac{\mu_0 NIR^2}{2((x - x_1)^2 + R^2)^{3/2}}$$

and by the second coil is:

$$B_2 = \frac{\mu_0 NIR^2}{2((x - x_2)^2 + R^2)^{3/2}}$$

The total field on the axis of a pair Helmholtz coils is equal to the sum of the field generated by coil 1 and coil 2, $B_{tot} = B_1 + B_2$
The distance d between the two coils is expressed as $d = pR$, where p is a freely varying positive parameter: $0 \le p \le 2$

Literature
Young & Freedman (2008).

Minds-On questions
- Predict the course of the magnetic field as a function of x for each individual coil.
- Based on the prediction of magnetic fields of both coils predict the resultant magnetic field.
- Execute the model and compare its results with your prediction.
- Use the Simulate option and investigate how the total magnetic field B changes depending on the distance between two coils.
- Adjust the parameter p in such a way as to reach optimum homogeneity over a maximum distance of the resultant magnetic field. What is the distance d needed to give the most uniform central magnetic field?
- How does the region of uniform magnetic field vary with:
  - the radius of the Helmholtz coils R?
  - the number of coil turns N?
  - the current carried in the coils I?
- Extend the model with two coils at the orthogonal y-axis and discuss the results.

Analysing student activities

In this experiment students use the given below model. The model calculates and displays magnetic field B.

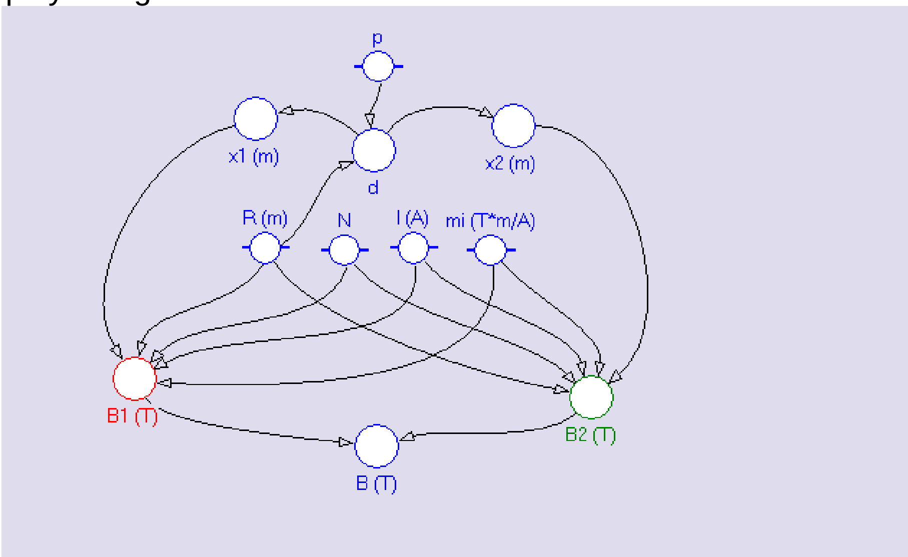


Figure 30. Model for field B

The following values are used in the model:

R=0.10 m

I=50 A

N=1000

$\mu_0 = 4\pi \cdot 10^{-7}$

By changing parameter p students investigate how the total magnetic field B changes depending on the distance between the coils. By adjusting the parameter p they have to find a maximum distance to reach optimum homogeneity of this field. By using the Simulate option students can change the current, number of turns and radius of each individual coil and observe the resulting B(x) graph.

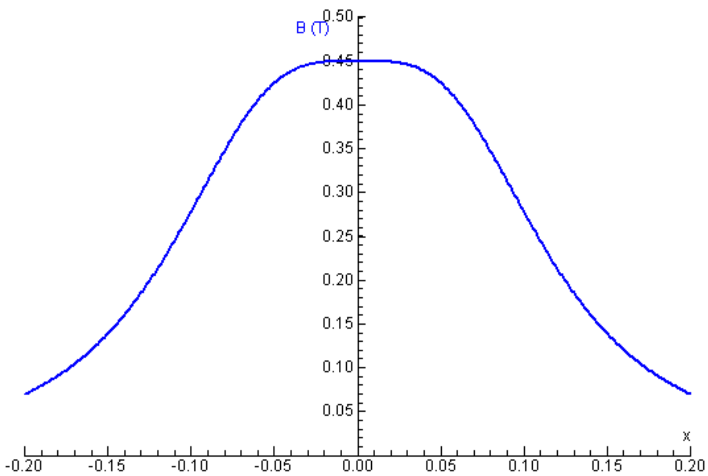


Figure 31. Graph of B(x) for p=1

Available Coach Activities: 359M_Field in Helmholtz coils.cma

Available Coach Results: 359M_Field in Helmholtz coils.cmr

Experiment 3.6.7.M: Magnetic Inclusion: Charge Trap

Chapter
3. Magnetism
3.6. Lorentz force

Link to other SC family files
Online learning modules: Module Magnetism, Slide 23/33

Learning objectives

- Illustrate the potential of the Lorentz force to trap charged particles in inhomogeneous magnetic fields.

Applied ICT technology
Modelling

Experiment setup
The parallel wires y = ±d both carry a current I in the positive x-direction and are a distance 2d apart. As a result, the magnetic field in the xy-plane experienced by the electron is directed along the z-direction.
Moving charge particle (charge q, mass m) is subjected to the Lorentz force, due to the interaction of its own moving charge and the combined magnetic field B of the two wires.

Figure 32. Parallel current-carrying wires

The physics of the experiment
Magnetic field at a distance r from a wire carrying a current I is given by:

$$B(y) = \frac{\mu_0 I}{2\pi r} = \frac{2x10^{-7} \cdot I}{r}$$

A particle at position y is a distance $r_1 = d - y$ removed from the upper wire (1)
and a distance $r_2 = d + y$ from the lower wire (2).

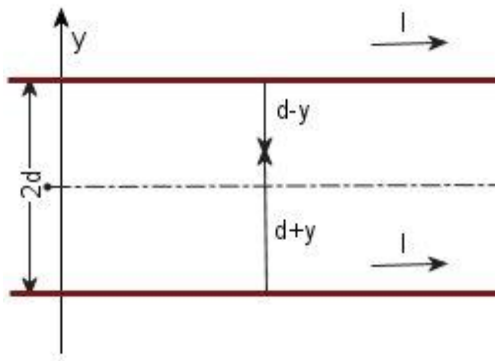


Figure 33. Particle position y

Superposition of the B-fields of both wires consequently yields:

$$B(y) = 2x10^{-7} \cdot I \cdot (\frac{1}{d-y} - \frac{1}{d+y})$$

The minus sign arises from the fact that the lower wire (2) creates a B-field in the positive z-direction, opposite to the B-field created by the upper wire (1) in the negative z-direction.

A good drawing is vital to explain the situation to the students. Even so, not every student can be expected to derive the formula himself.

The Lorentz force is determined by the vectorial cross product $\vec{F}_L = q \cdot \vec{v} \times \vec{B}$, so it has a magnitude $F_L = q \cdot v \cdot B$. In the below, we assume a positive B-field.
For a velocity v_y in the positive y-direction, F_L is by well known rules of thumb directed along the positive x-direction; similarly for a velocity v_x in the positive x-direction, F_L points in the negative y-direction.
This gives rise to the decomposition $F_x = q \cdot v_y \cdot B$ and $F_y = -q \cdot v_x \cdot B$ while $F_z = 0$.

The cross product and the corresponding decomposition itself will not be understood by the students. However, the result of the decomposition can convincingly be made plausible by the above argument using separate v_x and v_y in the case of a B-field in the positive z-direction.

For smaller values of y, the relation $F_y = -ky$ (with k an effective spring constant), is a good approximation.

As a result, the oscillation period is determined by $T = 2\pi\sqrt{\frac{m}{k}}$.

This line of thought should not offer any problem to the students.

Minds-On questions

- What happens if the initial electron velocities v_x and v_y are adapted? Will the trap always work or are there limits to the trapping power?
- What would happen if either the distance d or the current I are altered? Is there a relation between them such that they may be changed without changing the beam trajectory?
- Display the restoring force F_y as a function of y. The behaviour is almost linear:. Why is this connected to the sinusoidal trajectory, and what may be the consequences if the restoring force significantly deviates from a linear behaviour?
- Fit the trajectory to a mathematical function and deduce the frequency of the oscillation.
- Explain why the initial value of v_y will influence the amplitude of the oscillation, but not the period.
- Both v_x and v_y change as a function of time. What happens to the total velocity $v = \sqrt{v_x^2 + v_y^2}$. Explain!
- Sketch the magnetic field lines in case of two parallel wires.
- Sketch the magnetic field lines in case of two converging wires.
- What is the role of the inhomogeneouty of the magnetic field in trapping a charged beam?
- Make a qualitative suggestion to improve the trapping effect.

Analysing student activities

Students are asked to complete the below model.

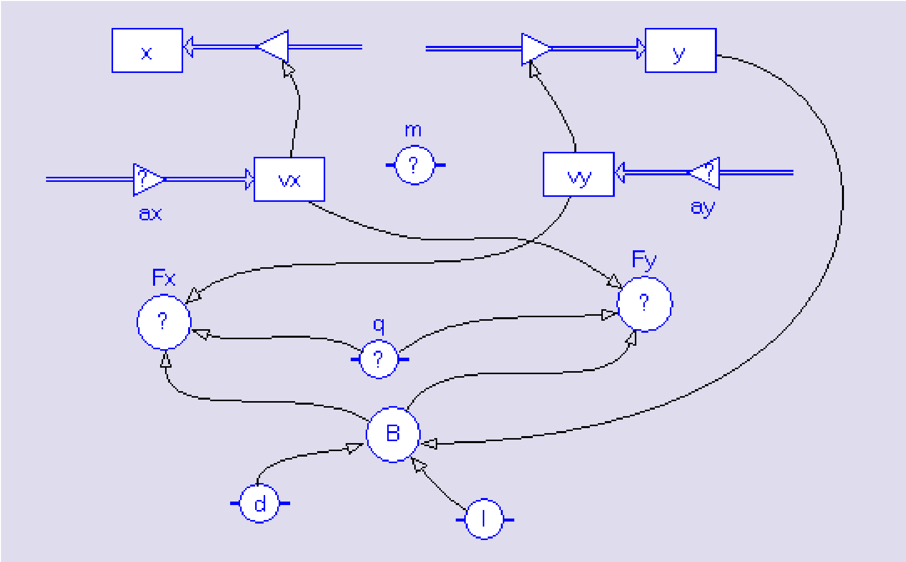


Figure 34. Model for completion

They will be able to insert the values of q and m first. Next, the basic expressions for a_x and a_y have to be completed, without the support of relational arrows. Finally, the expressions for F_x and F_y are to be completed, but as it concerns a new decomposition, relational arrows are given for support.

When an electron beam is guided through a magnetic field originating from two parallel wires directed along the y-axis, the beam will oscillate harmonically in the x-direction.

The model 'Trapped in between wires' shows the (modelled) operation of an elementary 2-D charge trap.

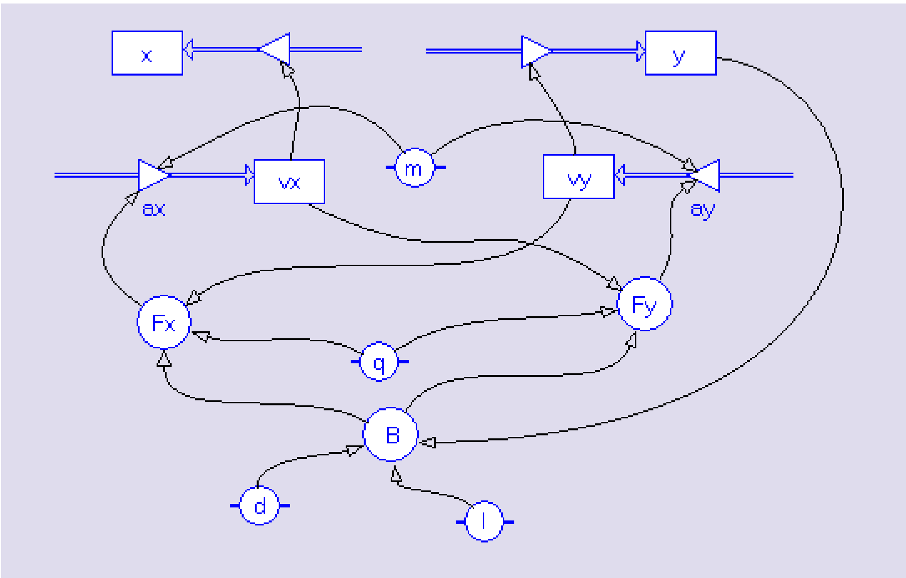


Figure 35. Coach model 'Trapped in between wires'

In the model, an individual electron (charge q, mass m) is subjected to the Lorentz force (decomposed into F_x and F_y), due to the interaction of its own moving charge and the combined magnetic field B of the two wires.
The parallel wires y = ± d both carry a current I in the positive x-direction and are a distance 2d apart. As a result, the magnetic field in the xy-plane experienced by the electron is directed along the z-direction.
The initial velocity of the electron is decomposed as v_x and v_y and can be altered (simulated) at wish to see the effect of an 'escape velocity' v_y.
The resulting trajectory is shown in the below diagram. Here, the wires are indicated by the bold lines.

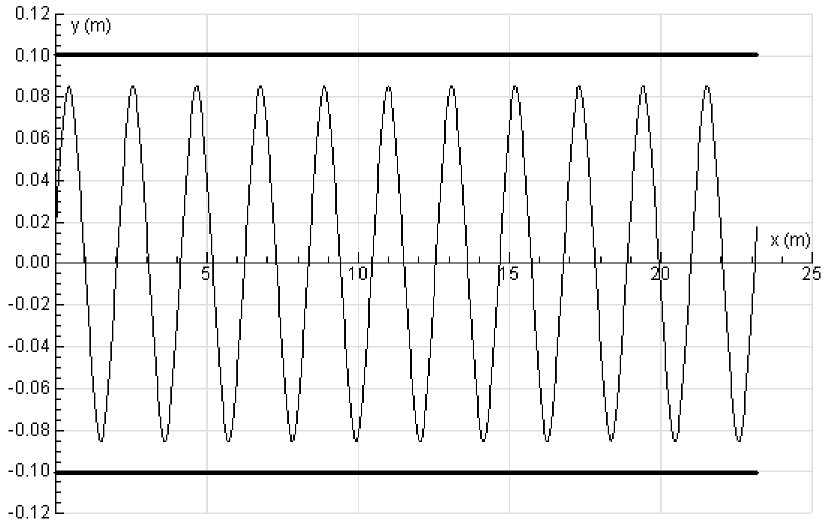


Figure 36. Electron trajectory

Apparently, the Lorentz force acts as a restoring force in the y-direction, with y=0 as the equilibrium position.

A more advanced model

As a first step towards the global understanding of the magnetic lens, the parallel wires are replaced by converging wires. The semi-distance d between the wires is now decreasing linearly.

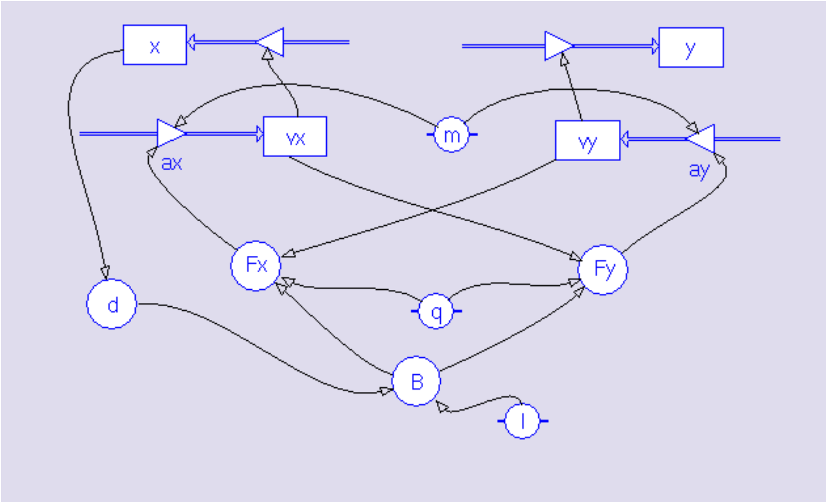


Figure 37. Coach model 'Trapped in between two converging wires'

As a result, the electron beam converges as well, though much slower. As the Lorentz force is orthogonal to the velocity, the kinetic energy remains constant. Therefore, reducing the amplitude will correspond to an increase in frequency of the oscillating electron.

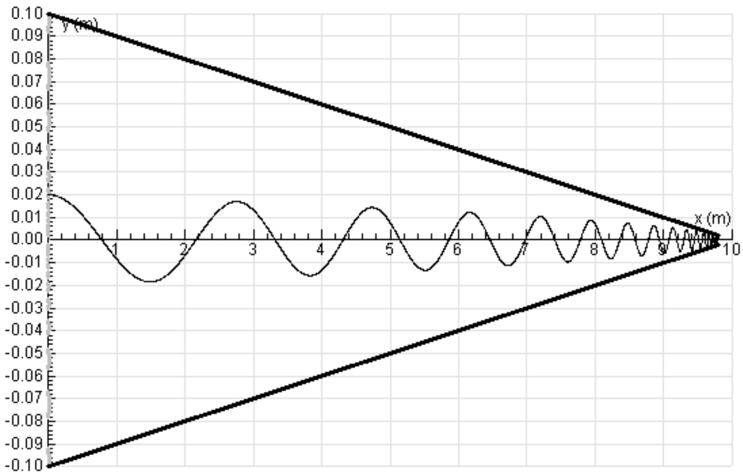


Figure 38. Electron beam convergence

Available Coach Activities: 367M_Trapped in between wires 01.cma
Available Coach Results: 367M_Trapped in between wires 01.cmr
367M_Trapped in between wires 02 - two converging wires.cmr

Simulations

Experiment 2.3.5.S: Magnet Falling in Copper, Aluminium and Plastic Tubes

Chapter
2. Electromagnetic induction
    2.3. Moving magnet

Link to other SC family files
Online learning modules: Module Induction, Slide 20
Modelling: Experiment 2.2.3.M Electromagnetic Induction by a Falling Magnet
Data acquisition: Experiment 2.2.3.D Electromagnetic Induction by a Falling Magnet

Learning objectives

- To use a simulation to investigate a falling magnet in a conducting, not magnetic tube. These investigations can later be applied towards exploring how real magnets fall in tubes of e.g. copper/aluminium in a laboratory.

Applied ICT technology
Simulation

The simulation shows a falling magnet in a conducting, not magnetic tube.

Model
The model of the simulation is given by the ordinary differential equation

$$m\frac{dv}{dt} = mg - kv$$

where g is the acceleration of gravity, m and V are mass and velocity of the falling magnet and k is a damping coefficient.

$$v(t) = \frac{mg}{k}\left[1 - e^{\frac{-kt}{m}}\right]$$

m = 3g,

$$k = \frac{\sqrt{2}}{\pi^2}\phi_0^2\sigma\sqrt{\frac{\ln^3(r_{out}/r_{in})}{r_{out}^2 - r_{in}^2}}$$

r_{in} = 6 mm (inner radius of a tube)
r_{out} = 7,5 mm (outer radius of a tube)
$\sigma = 59\cdot10^6\ \Omega^{-1}m^{-1}$ (tube conductivity)
Φ_0 = 27mW (maximum flux of a falling magnet radius 4,5 mm and high 5mm, m= 3g)

By replacing the magnet discs with point monopoles of the same net charge q_m, the flux through a ring a distance z from the nearest monopole can be given by

$$\phi_z = \frac{\mu_0 q_m}{2}\left[\frac{z+h}{\sqrt{(z+h)^2 + r_{in}^2}} - \frac{z}{\sqrt{z^2 + r_{in}^2}}\right]$$

where h is the height of the magnet and μ_0 is the permeability of free space. Then from Faraday's law:

$$\varepsilon_z = -\frac{d\phi_z}{dt}$$

Assuming the length of the tube to be divided into rings each of height x and that the resistivity of the copper is ρ the total resistivity R is given

$$R = \frac{2\pi r_{in}\rho}{tx}$$

so the current could be expressed as

$$I_z = \frac{\mu_0 q_m r_{in}^2 v^2}{2R}\left[\frac{1}{(z^2 + r_{in}^2)^{\frac{3}{2}}} - \frac{1}{[(z+h)^2 + r_{in}^2]^{\frac{3}{2}}}\right]$$

whereby the magnets are falling under gravity at terminal velocity and the change of gravitational potential energy is equal to the rate of dissipation of electrical energy:

$$mgv = \sum_z I_z^2 R$$

Since, in general, I^2R is electrical power:

$$P = \left[\frac{\mu_0 q_m r_{in}^2 v^2}{2R}\right]^2 \int_{-\infty}^{\infty} \frac{dz}{x}\left[\frac{1}{(z^2 + r_{in}^2)^{\frac{3}{2}}} - \frac{1}{[(z+h)^2 + r_{in}^2]^{\frac{3}{2}}}\right]^2$$

Then:

$$v = \frac{8\pi m g \rho r_{in}^2}{\mu_o^2 q_m^2 t \cdot f\left(\frac{h}{r_{in}}\right)}$$

$$f(x) = \int_{-\infty}^{\infty} dy\left[\frac{1}{(y^2 + 1)^{\frac{3}{2}}} - \frac{1}{[(y+x)^2 + 1]^{\frac{3}{2}}}\right]^2$$

$$q_m = \frac{2\pi B r_{mag}^2 \sqrt{h^2 + r_{mag}^2}}{\mu_0 h}$$

Visualization

The computer displays a schematic visualization of a transparent metal tube with a falling magnet moving inside. Small dots representing electrons are also visible. In a separate window, the program displays graphs of position vs. time and velocity vs. time. The interaction field is also presented.

Interaction

The student is able to change the material the tube is made of, the radius of the tube and the properties of the falling magnet.

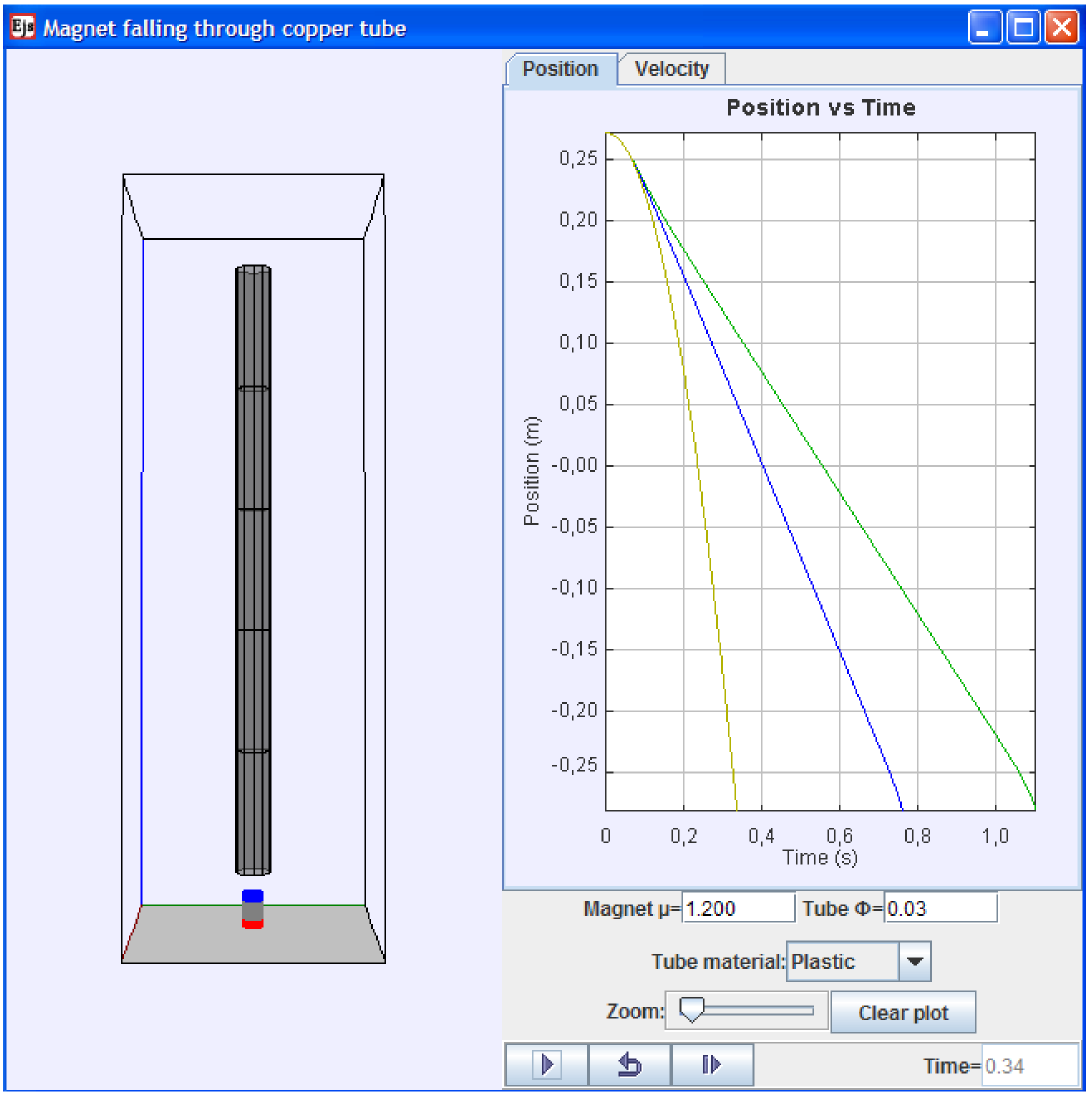


Figure 39. EJS simulation for magnet falling through copper tube

Proposed Student Activities

Activity 1

The student will be asked to find like the time of the fall changes with a magnet's properties while observing position vs. time and velocity vs. time dependence for.

Activity 2

The student will be asked to change the tube's radius and material and investigate how it affects the motion.

Literature

Ireson & Twidle (2008).

Minds-On questions

- Explain the change in the induced emf as the dropping height of the magnet is increased.
- How does changing the properties (size, strength) of the falling magnet influence the induced emf?
- How is the induced emf affected by changing the tube material?
- How does a change in the tube radius influence the induced emf?

Analysing student activities

The student will be asked to find like the time of the fall changes with a magnet's properties while observing position vs. time and velocity vs. time dependence for.

The student will be asked to change the tube's radius and material and investigate how it affects the motion.

Experiment 3.4.3.S: Component of magnetic field

Chapter

3. Magnetism

3.4. Earth magnetic field

Link to other SC family files

Online learning modules: Module Magnetism, Slide 3, 11

Learning objectives

- To use a simulation to explore a compass needle behavior when it is placed in the external magnetic field *B*.

Applied ICT technology

Simulation

Model

The angular position of the needle is described by the angle Θ.

Its angular velocity ϖ and angular acceleration α are described by motion equations:

$$\varpi = \Delta\Theta/\Delta t \text{ and } \alpha = \Delta\varpi/\Delta t$$

From Newton's 2nd law for circular motion $\alpha = \tau/I$ where τ is the torque which tends to align the needle along the magnetic field *B* and *I* is is the moment of inertia of the needle which can be estimated as $mL^2/12$ where *L* is the length of the needle.

Torque τ acting on the needle is $\tau = -\mu B sin\Theta \cong -\mu B\Theta$ for small values of Θ.

By analogy to Newton's law $a=F/m$ and Hook's law for a spring $F=-kx$ for which the period of oscillations is given by $T=2\pi * sqrt(m/k)$, the needle placed in the magnetic field *B* and displaced from equilibrium undergoes oscillations with period $T=2\pi * sqrt(I/\mu B)$.

The dipole of the compass is influenced by a dipole magnet. This influence depends on the distance and is visible because the compass turns towards the dipole, deflecting from its original N-S direction. The N-S direction is due to the earth's magnetic field, of which the strength can be estimated.

Visualization

A rather big compass is directed S-N in its initial position. A straight line is drawn, perpendicular to the compass axis. Along this straight line a dipole can be moved towards the compass. As it comes nearer, the compass is deflected from its initial position towards the dipole. This angle (from initial position of the compass to actual position), should be indicated.

Interaction

Setting the strength of the dipole to different values is possible. The dipole is movable along the straight line. The graph is visuable.

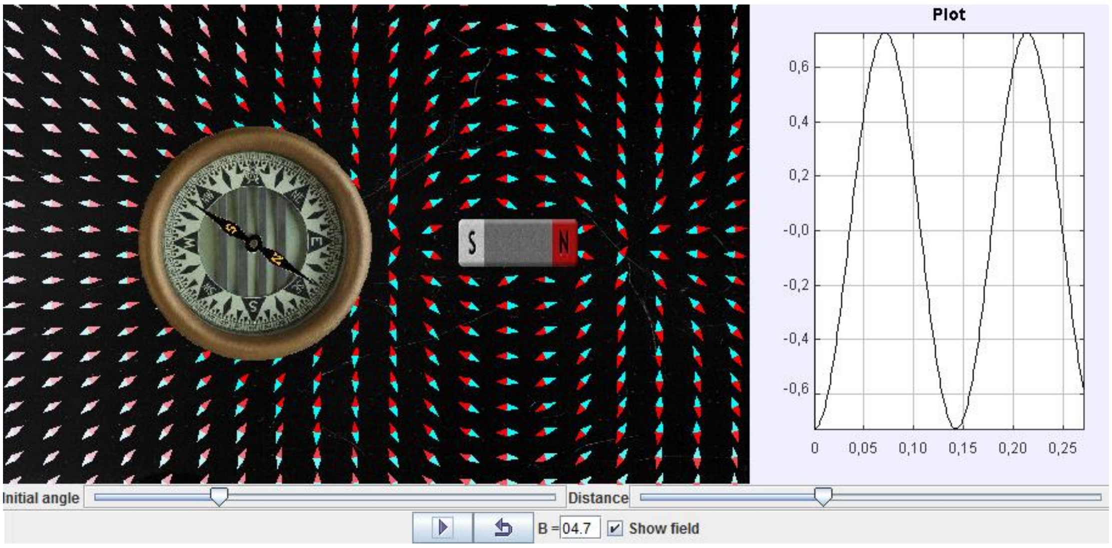


Figure 40. EJS simulation for magnet falling through copper tube

Proposed Student Activities

Activity 1

The student will be asked to put the dipole at different locations along the straight line and predict what happens as it comes nearer to the compass.

Activity 2

The student should try to predict the shape of the (distance, angle) graph.

Activity 3

The student should repeat this for different strengths and lengths of the magnet.

Minds-On questions

- How does a change of the magnetic field B influence the period of compass needle oscillations?
- Which properties of the needle influences the period of needle oscillations?

Experiment 3.5.9.S: Field in Helmholz Coils

Chapter
3. Magnetism
3.5. Magnetic effect of current

Link to other SC family files
Online learning modules: Module Magnetism, Slide 34-35
Modelling: Experiment 3.5.9.M: Field in Helmholtz Coils

Learning objectives

- To use a simulation to supports the exploration of the homogeneity of the magnetic field between two identical coils as a function of their distance.

Applied ICT technology
Simulation

The simulation shows Helmholtz coils setting up a homogeneous magnetic field.

Model
The model of the simulation is given by the addition of the magnetic fields of two separate coils, each given by the Biot-Savart law: the field at a point P of the axis of a single circular current loop is given by: $B_P = \frac{1}{2}\mu_0 \frac{I}{R}\sin^3\alpha = \frac{1}{2}\mu_0 \frac{I}{R}\left(\frac{R}{r}\right)^3$.

Where:

- $\mu_0 = 4\pi \cdot 10^{-7} =$ magnetic permeability of the vacuum
- *R* is the radius of the coils
- $r = \sqrt{x^2 + R^2}$ is the distance between P and the current loop

If the coils, each having *N* turns or windings, are positioned at $x_1 = -\frac{1}{2}d$ and $x_2 = \frac{1}{2}d$ of the *x*-axis, so that the origin is at the centre of the two coils, one obtains:

$r_1 = \sqrt{(x - x_1)^2 + R^2} \rightarrow B_1 = \frac{\mu_0 NI}{2R}\left(\frac{R}{r_1}\right)^3$ and similarly:

$r_2 = \sqrt{(x - x_2)^2 + R^2} \rightarrow B_2 = \frac{\mu_0 NI}{2R}\left(\frac{R}{r_2}\right)^3$, the final result at any point *x* being $B = B_1 + B_2$.

The distance *d* between the two coils is expressed as $d = \gamma R$, where γ is a freely varying positive parameter: $0 \le \gamma \le 2$.

Visualization

The computer displays a schematic visualization of two identical coils with a variable distance. In a separate window, the program displays a graph of the total magnetic field vs. distance.

Interaction

The student should be able to change the current, number of turns and radius of each individual coil. The student is asked to investigate for what value of the parameter γ, the resultant magnetic field will optimally homogeneous.

To do this, the student has to make a model from the above equations, with *x* as independent variable. The model calculates and displays *B* for $-d \le x \le d$.

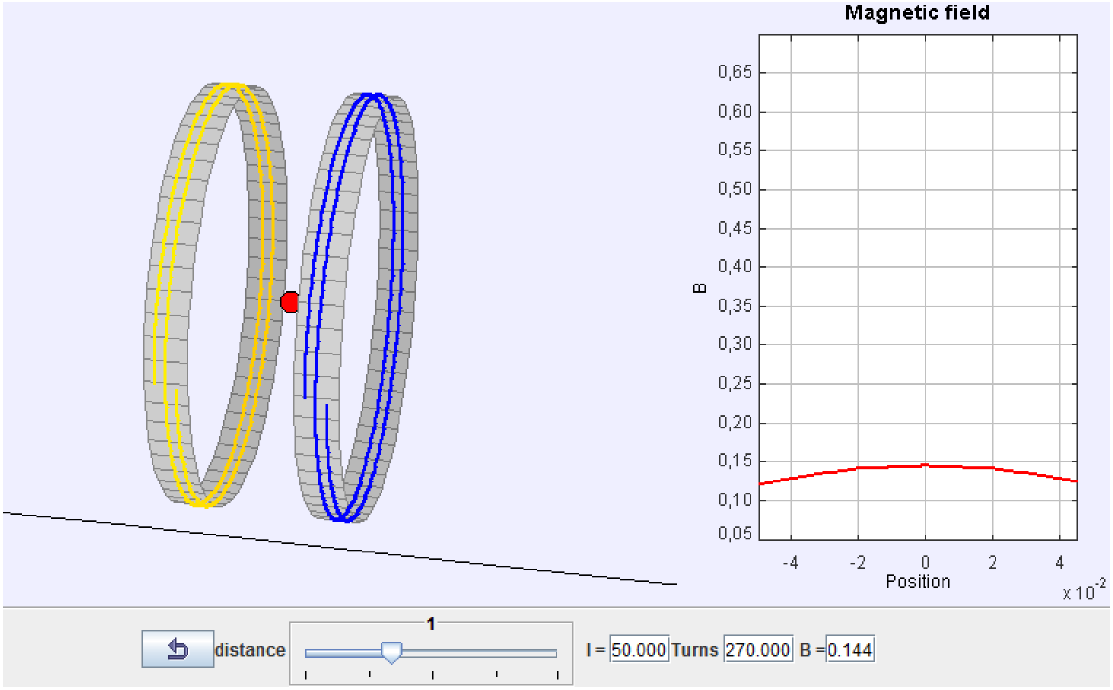


Figure 41. EJS simulation for field in Helmholz coils

Proposed Student Activities

Activity 1

Predict the course of the magnetic field as a function of x for each individual coil, to predict (there from) the resultant magnetic field there from and to comment on the symmetry of the setup.

Activity 2

Adjust the parameter γ in such a way as to reach optimum homogeneity over a maximum distance of the resultant magnetic field.

Activity 3

Extend the model with two coils at the orthogonal y-axis and discuss the results: improvement or not?

Activity 4

Compare with and discuss results from the corresponding Modelling activity.

Literature

Einstein, Albert. [Review of Hermann von Helmholtz. Zwei Vortrage uber Goethe. W. Konig, ed. (Braunschweig: Vieweg, 1917).] Die Naturwissenschaften 5 (1917): 675. As quoted in: David Cahan's 666-page book Hermann von Helmholtz and the Foundations of Nineteenth-Century Science (pg. v).

Minds-On questions

- Predict the course of the magnetic field as a function of x for each individual coil.
- Based on the prediction of magnetic fields of both coils predict the resultant magnetic field.
- Execute the simulation and compare its results with your prediction.

Data Acquisition

Experiment 1.2.4.D: R(T) for a Bulb

Chapter

1. Conduction
    1.2. Conduction and temperature

Link to other SC family files

Online learning modules: Module Conduction, Slide 32/35

Modelling: Experiment 1.2.4.D: R(T) for a Bulb

Learning objectives

- Recording the I(U) characteristic of a light bulb.
- Determining the relation between resistance and temperature of a bulb filament.

Applied ICT technology: Data Acquisition

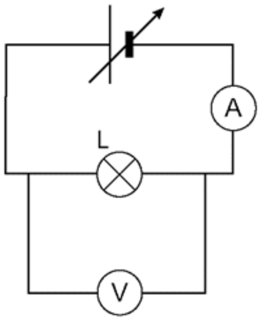


Figure 42. Bulb circuit

Experiment description

In this experiment a current-voltage characteristic of a light bulb is studied. Students use voltage and current sensors to measure a voltage across the bulb and a current carried through the bulb.

Materials needed

- An interface
- Voltage sensor
- Current sensor
- Variable power supply (e.g. 0-12V)
- Bulb (e.g. 12 V, 3W)
- Resistor (e.g. 10 Ω)

During the measurement the power is gradually varied from 0 to 12 Volt. To avoid transient phenomena due to the heating of the lamp, each measurement should be taken after the

values of voltage and current have been stabilized.
From processing the measurement data the relation between resistance (resistivity) and temperature of a bulb filament is obtained.

Tips:
Ideally, one would also like to measure the filament temperature directly for a number of different voltages by means of a so-called disappearing filament pyrometer, shown on the photo.

The physics of the experiment
The electrical resistance R of a conductor is defined as the ratio of the potential difference, or voltage V applied across the conductor to the current I passing through it: $R = \frac{U}{I}$

If the conductor is made of a homogeneous material formed into a shape of uniform cross-sectional area S and length L, the resistance can be expressed in terms of these dimensions and an intrinsic property of the material called its resistivity: $R = \frac{\rho L}{S}$ and $R = \frac{\rho L}{\frac{1}{4}\pi d^2}$ where d is the diameter of the filament.

The resistivity can be calculated from $\rho = \frac{\pi d^2 R}{4L}$.

The resistance of the bulb changes because the filament heats up, and the resistivity of the filament material depends on its temperature.

Assuming equilibrium between the supplied electrical power and the outgoing radiative power obeying the Stefan-Boltzmann T^4 law,

$$P_{el} = P_{rad}$$

$$U \cdot I = A \cdot \sigma T^4$$

the filament temperature for each particular voltage value can be determined for each given value of U and I by $T = \sqrt[4]{\frac{U \cdot I}{A \cdot \sigma}}$, where $\sigma = 5.67x10^{-8} Wm^{-2}K^{-4}$ is the constant of Stefan-Boltzmann.

A is the effective radiating area $A = f \cdot \pi \cdot d \cdot L$ and $0 < f < 1$ is a fraction describing the effective radiating area and, to a lesser degree, the filament greyness.

In practice, $f \approx 0.3$ [2] but obviously independent temperature measurements are necessary to determine f more accurately.

Literature
Leff (1990), Shackelford (1916), Santi & Michelini (2006) and Wagner (1991).

Minds-On questions

1. What is the relation between a current I carried through the bulb and the voltage across the bulb U?
2. What is the resistance R of the bulb filament?
3. What is the resistivity of the bulb filament ρ?

a. For this you need to know the length and diameter of the bulb filament.

2. What is the supplied electrical power P_{el}?
3. Assume that the system is in dynamical equilibrium conditions in which all electrical energy supplied to the system is emitted as electromagnetic radiation $P_{el} = P_{rad}$.

   a. Calculate the temperature T(K) of the filament and create a diagram of ρ(T).
4. What is the relation between the resistivity and the temperature of the filament?

Analysing student activities

Student measure current I carried through the bulb and the voltage across the bulb (U) for various voltages U (0 to 12 V). Then they determine the resistance R and the resistivity ρ.

Based on an assumption that the system is in dynamical equilibrium conditions in which all electrical energy supplied to the system is emitted as electromagnetic radiation $P_{el} = P_{rad}$, they calculate T(K) and find the relation between ρ and T.

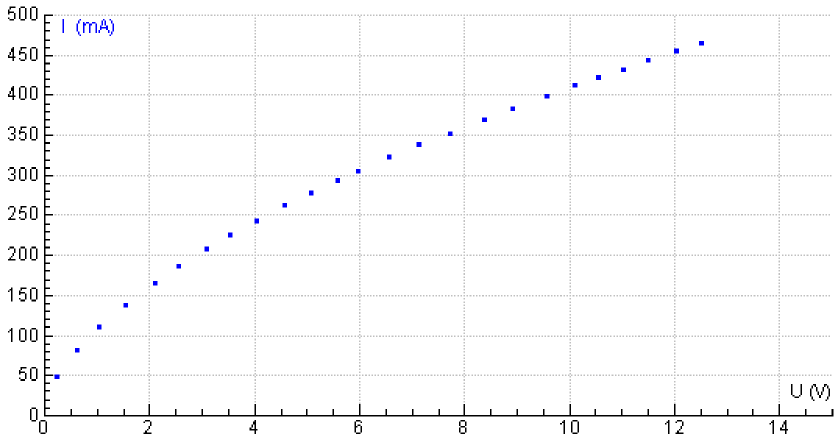


Figure 43. Example I(U) characteristic

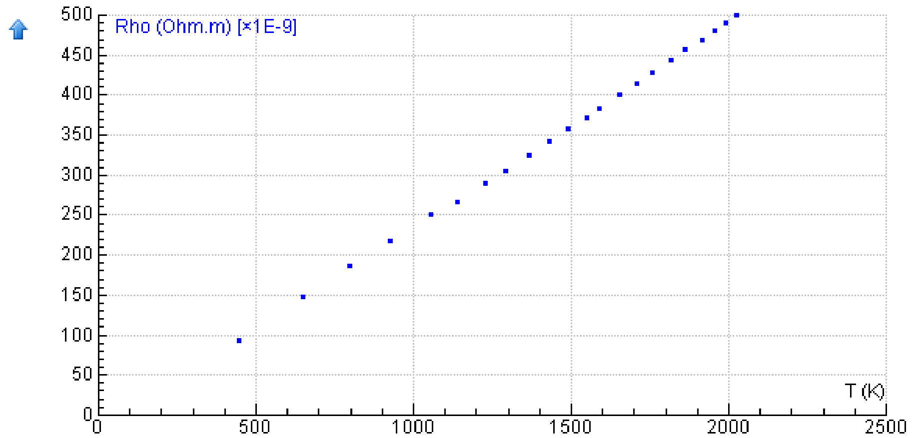


Figure 44. Example graph of ρ(T)

The relation between resistivity ρ and temperature T is linear.

Available Coach Activities: 124D_R-T bulb.cma
Available Coach Results: 124D_R-T bulb.cmr

Experiment 2.2.3.D: Electromagnetic Induction by a Falling Magnet

Chapter

2. Electromagnetic induction
   2.2. Moving magnet

Link to other SC family files

Online learning modules: Module Magnetism, Slide 23-30/45
Modelling: Experiment 2.2.3.M Electromagnetic Induction by a Falling Magnet

Learning objectives

- Measure voltage induced by the motion of a magnet falling through a coil.
- Investigate how the induced voltage is affected by reversing a magnet, changing the speed of magnet or using magnets of different strengths.
- Determine the change of magnetic flux during the magnet's fall.

Applied ICT technology

Data Acquisition

Experiment setup

- CoachLab II interface
- Voltage sensor or 4-mm connecting wires when using the CoachLab II interface
- Coil(s) (for example coil with 1600 turns)
- plastic tube which can be put through the coil
- retort stand
- magnet(s)

Experiment procedure

1. Place the coil on the plastic tube.
2. Attach the plastic tube to the lab stand.
3. Connect the voltage sensor to input 1 of an interface. When working with the CoachLab II interface you can use 4-mm wires instead of the voltage sensor.
4. Because this is a fast experiment, happen within half a second, triggering can be used. The program starts to record a graph only when the trigger conditions are met.

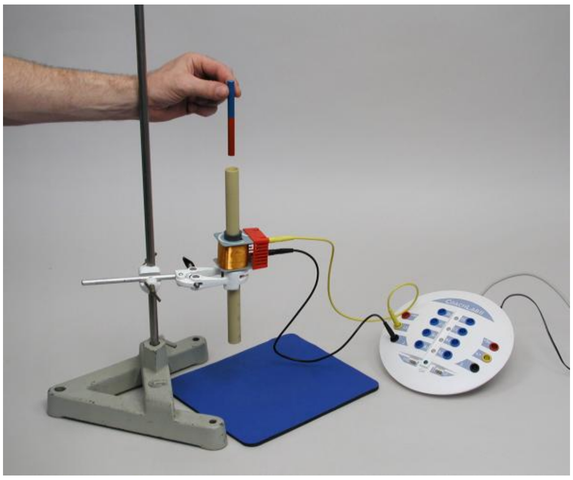


Figure 45. Experiment setup

5. Drop the magnet through the plastic tube. In Coach the measurement starts when the voltage signal reaches 0.3V, thus when you drop the magnet.
6. Use magnets with different strengths and repeat the experiment. Explain how the strength of the magnet affects the induced voltage.
7. Turn the magnet 180 degrees and investigate the effects on the measurement. Explain results.
8. Modify the angle of the plastic tube and investigate the effects on the measurement. Explain results.
9. Use two or three coils in series. Explain the shape of the induced voltage.

Tips

- If a value of the trigger level is too closed to zero recording can be started by noise of the signal. For this reason select the trigger level value not too close to zero.
- If the trigger level is set above the maximum (or below the minimum) voltage level of the signal then recording will never be started automatically. It is good exercise to change the trigger condition and observe its effect.
- The signals before and after the peaks may not be centred on zero volts. If so, there is slight offset in the voltage sensor. This does not affect your qualitative answers, but offset should be corrected for in calculations.

The physics of the experiment

When a magnet is falling through a coil, current is induced in the wire. This phenomenon is called electromagnetic induction.

According to Faraday's law, for a coil that consists of N loops, the induced emf ε is proportional to the negative of the rate of change of magnetic flux Φ

$$\varepsilon = -N\frac{d\Phi}{dt}$$

The direction of the induced current is determined by Lenz's law, the induced current produces magnetic field which tends to oppose the change in magnetic flux that induces such currents. (See also 2.2.1.M and 2.2.3.M activities).

The voltage induced across the ends of a coil when a magnet is falling through a coil is directly recorded in this experiment.

Minds-On questions

- Explain the shape (positive and negative peaks) of the recorded signal.
- Why the peaks are not symmetric?
- At which moment was the magnetic flux changing most quickly?
- What was the total change of magnetic flux during the first half of the magnet's fall - while it was moving in to the coil?
- What was the total change of magnetic flux during the second half of the magnet's fall - while it was moving out of the coil?
- How could you change your experiment to increase the magnitude of the signal?

Analysing student activities

Students measure the voltage induced in the coil when a magnet falls through a coil and determine the change of magnetic flux during the magnet's fall (by using the *Area* option or the *Integral* option).

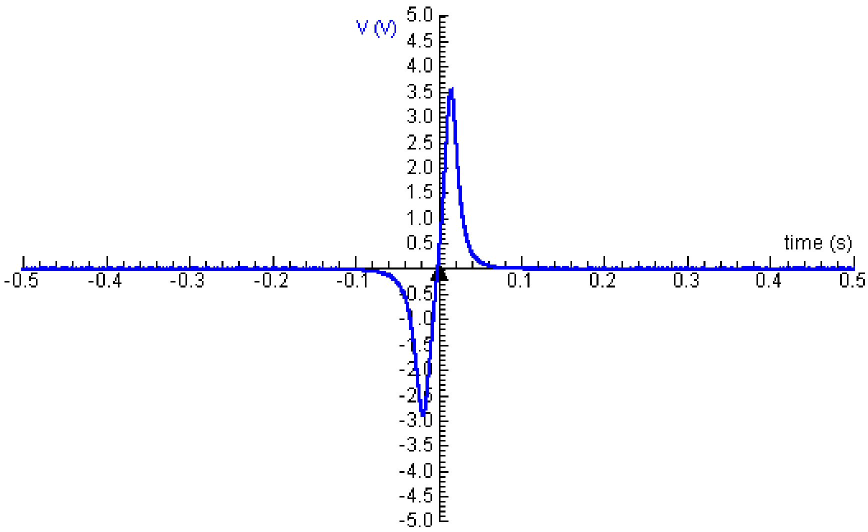


Figure 46. Example data: induced emf recorded for a neodymium magnet

Further students investigate how the induced voltage is affected by:

- reversing a magnet
- using magnets with different strengths
- changing the speed of the magnet

An interesting modification of this experiment can be using two or three coils in series.

Available Coach Activities: 223D_Electromagnetic induction by a falling magnet.cma
Available Coach Results: 223D_Electromagnetic induction by a falling magnet 1.cmr

Experiment 3.5.4.D: Field Inside Loop / Around Solenoid

Chapter

3. Magnetism
   3.5. Magnetic field of current

Link to other SC family files

Online learning modules: Module Magnetism, Slide 32/45

Learning objectives

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

Applied ICT technology
Data acquisition

Experiment setup
Magnetic sensor connected with Coach 6 system is situated in solenoid with current.

Materials needed

- Computer with Coach 6
- CoachLab II interface
- solenoid
- magnetic sensor
- ammeter
- wires
- generator of direct current

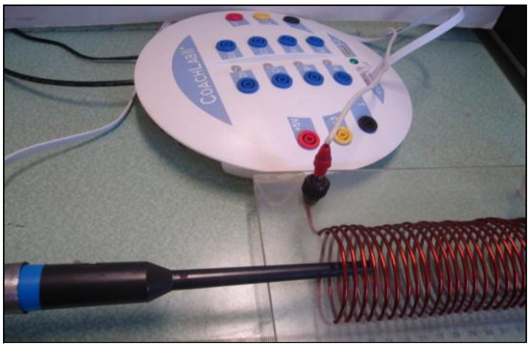


Figure 47. Necessary equipment

The physics of the experiment
Ampere's law can be applied to find the magnetic field inside of a long solenoid as a function of the number of turns per unit length *N/L* and the current ***I.*** The magnetic induction inside a solenoid which carries an electric current has magnitude given by $B = \mu_0 n I$ where

- $\mu_0 = 4\pi.10^{-7}$, H/m - magnetic permeability of the vacuum
- *N* total number of turns
- *L* length of solenoid
- *n* = *N/L* the number of turns per unit length
- *I* current, A
- *B* magnetic induction, T

The magnetic field inside a solenoid is proportional to both the applied current and the number of turns per unit length. There was no dependence on the diameter of the solenoid or even on the fact that the wires were wrapped around a cylinder and not a rectangular shape. By wrapping the same wire many times around a ferromagnetic cylinder, the magnetic field due to the wires can become quite strong.

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 of 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 magnitude of current in the wire?
- What happens with the magnetic field along the solenoid at direct current in the wire?
- What happens with the magnetic field in solenoid with ferromagnetic core?

Analysing student activities

Students are asked to complete the experimental equipment with Coach 6. They will be able to change the magnitude of electrical current in the loop and the position of magnetic sensor inside and outside the solenoid. The result did not depend on the precise placement of the sensor inside the solenoid, indicating that the magnetic field is constant inside the solenoid. Inside the coil the field is very uniform, and the field from a solenoid is essentially identical to the field from a bar magnet. The magnetic field generated in the centre, or *core*, of a current carrying solenoid is essentially *uniform*, and is directed along the axis of the solenoid. Outside the solenoid, the magnetic field is far weaker.

Experiment 3.5.7.D: Iron Core Vertically Attracted Inside a Coil

Chapter

3. Magnetism

3.5. Magnetic field of current

Link to other SC family files

Online learning modules: Module 3, Slide 41/45

Learning objectives

- Investigate magnetic field created from a coil with iron core as a function of current

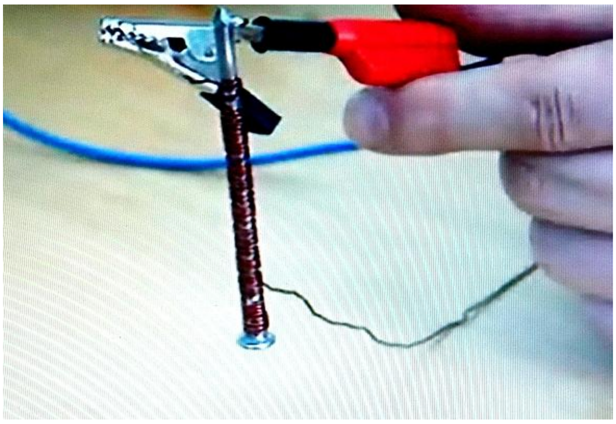


Figure 48. Experiment setup

Applied ICT technology

Animation – like video (VA)

Experiment setup

Wind an insulated copper wire around an iron nail, or use a coil with an iron core. Connect to a battery or other voltage source to make an electromagnet.

The physics of the experiment

Ampere's law can be applied to find the magnetic field inside of a long coil as a function of the number of turns per unit length *N/L* and the current ***I.*** By wrapping the same wire many times around a iron core, the magnetic field due to the wires can become quite strong. The magnetic induction inside a coil with iron core which carries an electric current has magnitude given by $B = \mu_0 \mu . nI$ where

- $\mu_0 = 4\pi.10^{-7}$, H/m - magnetic permeability of the vacuum
- μ - magnetic permeability (for iron $\mu = 5000$)
- *L* length of solenoid
- *n* = *N/L* the number of turns per unit length
- *I* current, A *and B* magnetic induction, T

The magnetic field generated in the centre, or *core*, of a current carrying coil is essentially *uniform*, and is directed along the axis of the coil. Outside the coil, the magnetic field is far weaker. Inside the coil the field is very uniform, and the field from a coil with iron core is essentially identical to the field from a bar magnet.

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 loop/around coil with the magnitude of current in the wire?
- What happens with the magnetic field along the coil with iron core at direct current in the wire?
- What happens with the magnetic field in coil with ferromagnetic core when the current is switched off?

Analysing student activities

The student will be asked to predict how several factors affect the course of the resultant magnetic field and to comment on the symmetry of the setup. The factors are: the current in the coil, the number of turns of wire and the shape of the iron core.

The student is asked to predict the course of resultant magnetic field as the current is increased and as the number of turns is increased. They have to explain why after a certain current and number of turns is reached, further increases in current or turns do not make the magnetic field stronger. The student is asked to explain the origin of magnetism in iron core applying the concept of Weiss domains.

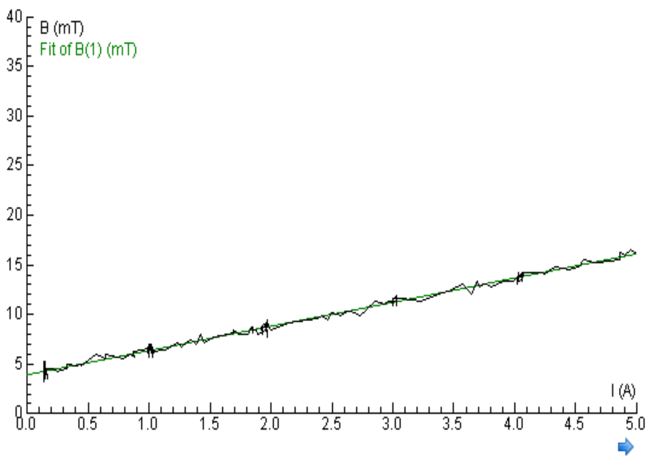


Figure 49. Example B(I) characteristic

The relation between magnetic induction B and current I in the solenoid is linear.
Available Coach Results: 354D_Solenoid_B(I).cmr

Experiment 3.3.7.VD: “Ski Jumping” in a Magnetic Field

Chapter

3. Magnetism

    3.3. Interaction based on permanent magnets

Link to other SC family files

Online learning modules: Module 3, Slide 23-30/45

Learning objectives

- Recognizing that the ball will be magnetized as a result of the magnetic field of the permanent magnet.
- Recognizing that the magnetic interaction is strongly distance dependent: it is only effective at short range and vanishes elsewhere.
- Recognizing the experiment as a demonstration of scattering from a central potential, unravelling the relation between impact parameter and scattering angle.
- Determining empirically the magnetic force between the ball and the magnet.

Applied ICT technology

Data Video and Modelling

Here students can

- record videos of experimental trials and analyse them in Coach
- use provided Coach activities with already recorded videos of experimental trials.

Experiment description

An inclined aluminium profile is placed on a smooth table. A permanent magnet is fixed to the table near the end of the aluminium 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.

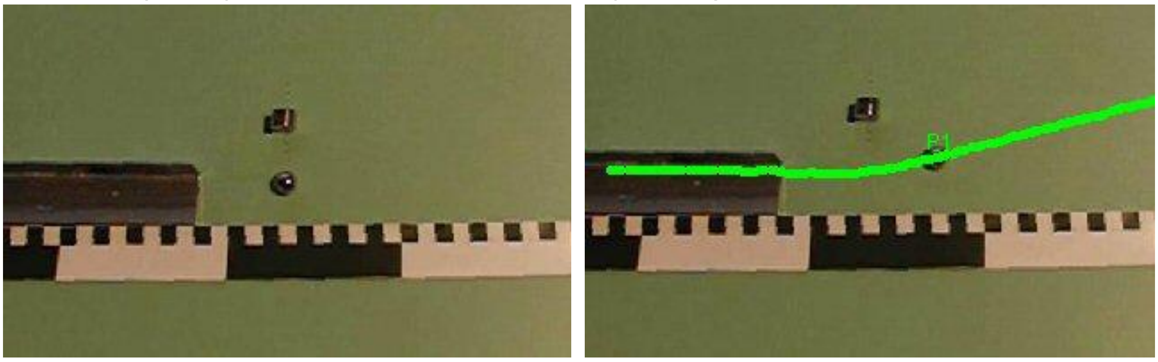


Figure 50. Trajectory of steel ball past magnet

The problem stated to students, how do a permanent magnet and ball (of ferromagnetic material) interact, when the ball moves towards the magnet in a direction parallel to the magnetic axis?

Materials needed

- A permanent magnet
- An aluminium profile
- An iron (or steel) ball
- A ruler or a piece of graph paper for video scaling
- Glue tape to fix a magnet to a table.
- Video camera (advised high speed camera)

Tips

- The aluminium profile can be fixed at the border of the table; this allows smother movement of the ball.
- Place the magnet 2-3 cm from the edge of the table.
- Place a ruler or graph paper so that you can easily make video scaling.
- Before each trial, please throw the iron ball on the table to reduce its reminiscent magnetization.
- The slope of the profile should be not too steep, and the profile can be a little bit rough to get the ball rolling instead of sliding.

The physics of the experiment

When a rolling iron ball (previously non-magnetized) passes along a permanent magnet, the ball changes its trajectory. In consequence of the magnetic attraction, the ball does not continue its straight path but is deflected under a ‘scattering’ angle θ.

An iron ball is a non-magnetized ferromagnetic object. In the presence of the magnetic field B of the permanent magnet, the alignment of the dipoles in the iron (steel) will produce a temporal magnetization.
Originally, the Weiss domains in the ball are randomly oriented and the net external magnetic moment of the ball is zero. When the ball comes into close range of the permanent magnet, the magnetic moments of the Weiss domains will be oriented along the magnetic axis of the magnet. This process involves both the displacement of the Bloch walls and the re-orientation of the magnetic moment vectors.

The speed and the completeness of the orientation process depend on the exact composition of the metal alloy. Naturally, if the magnetic orientation process is not fully completed during the passage, the magnitude of the magnetic force will be reduced.

Furthermore, the magnetic B-field of a permanent magnet may only approximately be described by a dipole field but is in fact geometry dependant. For these reasons we prefer to describe the experiment from a pure empirical point of view, assuming an a priori unknown inverse power law for the mutual magnetic force of the form $F(r) = \frac{c}{r^n}$

Here, both the constant c and especially the physically interesting exponent n will be determined through the combination of the experiment with a computer model.

As a first step, the relation between the impact parameter b and the deflection angle θ is determined experimentally, yielding an approximate relation

$$\theta = \frac{K}{b^m}.$$

For which m can be determined via the graph of $\log(\theta) = Log(K) - m\log(b)$. This equation demonstrates a linear relationship between log(θ) and log(b) in which the constant m is regarded as the gradient of a line.

In the second step, a computer model for the motion of the ball in the central potential field is used.

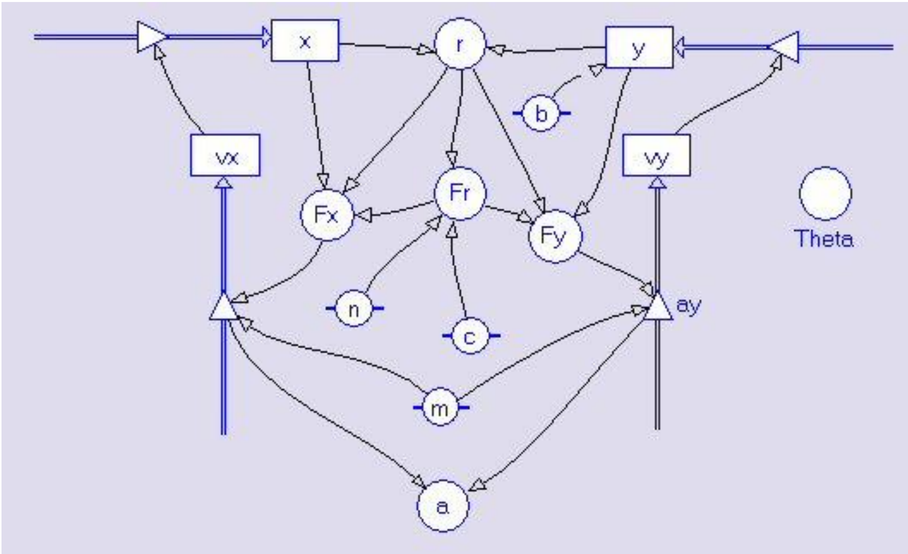


Figure 51. Model for motion of steel ball in central potential field

The force acting on the ball is expressed as $F(r) = \frac{c}{r^n}$ where c and n have unknown values. The constant c is determined for each possible value of n[1] by one of the experimental requirement of value b and corresponding value θ.

In the next step the models for different n-value (with its corresponding c value) are used to find the theoretical relation between θ and b. For each n-value the impact parameter b is varied and the θ calculated by the model.

The m-value is determined from the resulting θ (b) relation in the same way as for experimental data (via log(θ) versus log(b)). By comparison of theoretically found m-values with the experimentally determined m-value the best value of n can be concluded.

Detailed explanation with data is given in the 'Analysing student activities' part.

Minds-On questions

- How does the ball interact with magnet when it passes 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 parameter b and the deflection angle?
- Can you propose a formula which could describe the relation between F and r?

Analysing student activities

Students can make their own videos. For each video they change the distance between the magnet and the ball, they release a ball from the same height and record the motion of the ball.

In case the video recording is difficult to arrange then student can perform the experiment and then use the videos given the Coach activities.

There are 7 Coach activities in which videos of 7 experimental trials. IN each trial the distance between the magnet (b varied between 3.0 and 4.5 cm) and the passing ball are recorded with a high speed camera (210 frames per second). The mass of the ball used in the recorded experiment is 8.56 g. Data from these activities are used in the analysis below.

In each video analysis the distance between the magnet and the moving ball (the impact parameter b) and the deflection angle θ are measured.

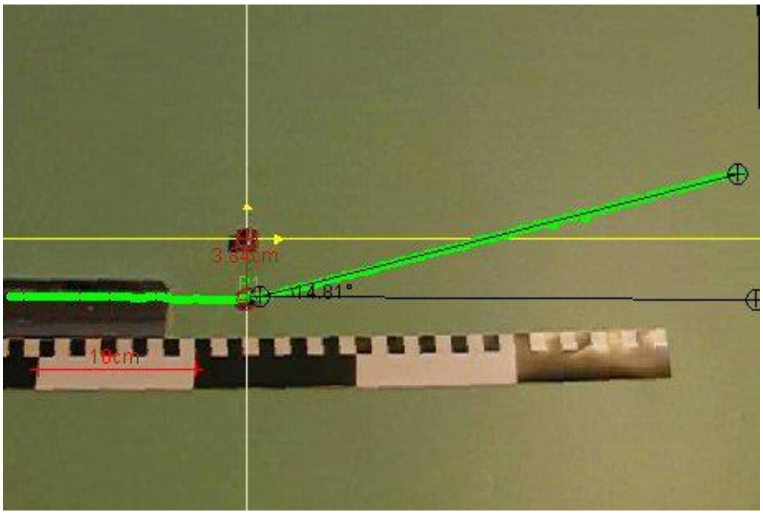


Figure 52. Video measurement of the magnet-ball distance and deflection angle, in this case b=0.0384 m and θ = 14.81 degree

The approximate relation between b and θ is:

$\theta = \frac{K}{b^m}$, for which m can be determined via log(θ) versus log(b) graph. For our data m ≈ 7.

In the next step the model is used.

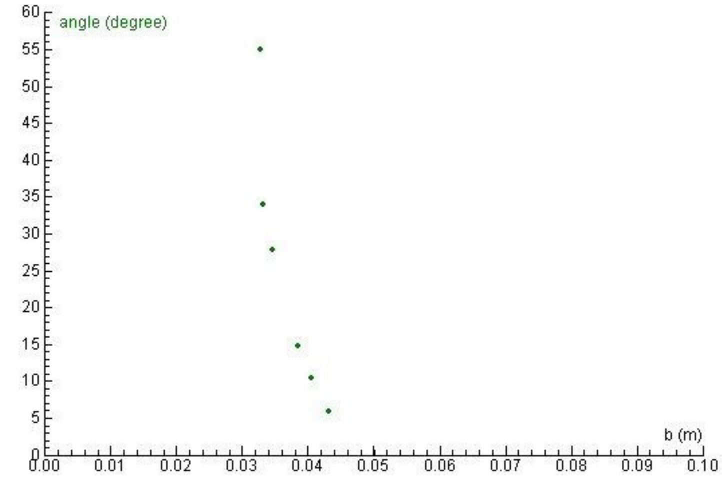


Figure 54. Plot of θ vs b

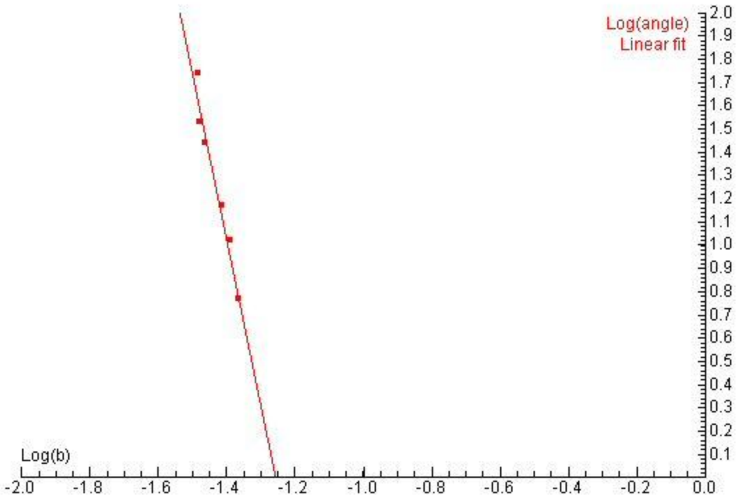


Figure 55. Plot of log(θ) vs log(b)

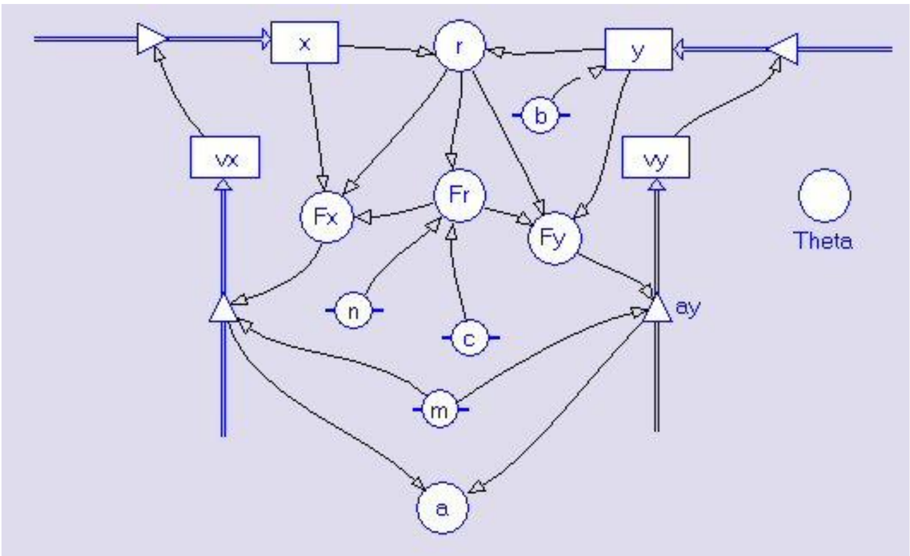


Figure 56. Model of force

In this model force is described by $F(r) = \frac{c}{r^n}$ where c and n have unknown values.

The constant c is determined for each possible value of n by the experimental requirement: b = 0.0384 m $\rightarrow \theta$ = 14.81 degree.

b(m)	Angle θ (degree)
0.0328	54.92
0.0331	33.99
0.0346	27.75
0.0384	14.81
0.0406	10.44
0.0431	5.91

n	m
3	2.4
4	3.8
5	6.8
6	8.2
7	10.9

n	c
3	$6.2 \cdot 10^{-7}$
4	$2.5 \cdot 10^{-8}$
5	$1.05 \cdot 10^{-9}$
6	$4.45 \cdot 10^{-11}$
7	$1.8 \cdot 10^{-12}$

In the next step the models for different n-value (with its corresponding c value) are used to find the theoretical relation between θ and b. For each n-value the impact parameter b is varied and the value of θ is calculated by the model. The m-value is determined from the resulting theoretical θ (b) graph in the same way as the experimental value of m was found (via log(θ) versus log(b) graph).

$m_{experimental} = 7$

By comparison of theoretically found m-values with the experimentally determined m-value the best value of n can be concluded. The results here strongly suggest n = 5 as the most suited power value. The force acting between the magnet and the passing iron ball in this experiment can be described by the formula $F(r) = \frac{1.05 * 10^{-9}}{r^{-5}}$.

Available Coach activities

337VD_Ski jumping 01 - trial 1.cma
337VD_Ski jumping 02 - trial 2.cma
337VD_Ski jumping 03 - trial 3.cma
337VD_Ski jumping 04 - trial 4.cma
337VD_Ski jumping 05 - trial 5.cma
337VD_Ski jumping 06 - trial 6.cma
337VD_Ski jumping 07 - trial 7.cma
337VD_Ski jumping 08 - experimental relation angle-b.cma
337VD_Ski jumping 09 - model.cma
337VD_Ski jumping 10 - theoretical relation b-theta.cma

Available Coach results

337VD_Ski jumping 01 - trial 1.cmr
337VD_Ski jumping 02 - trial 2.cmr
337VD_Ski jumping 03 - trial 3.cmr

337VD_Ski jumping 04 - trial 4.cmr
337VD_Ski jumping 05 - trial 5.cmr
337VD_Ski jumping 06 - trial 6.cmr
337VD_Ski jumping 07 - trial 7.cmr
337VD_Ski jumping 08 - experimental relation angle-b.cmr
337VD_Ski jumping 09 - model n=3.cmr
337VD_Ski jumping 10 - model n=4.cmr
337VD_Ski jumping 11 - model n=5.cmr
337VD_Ski jumping 12 - model n=6.cmr
337VD_Ski jumping 13 - model n=7.cmr
337VD_Ski jumping 14 - theoretical relation b-theta for n=3.cmr
337VD_Ski jumping 15 - theoretical relation b-theta for n=4.cmr
337VD_Ski jumping 16 - theoretical relation b-theta for n=5.cmr
337VD_Ski jumping 17 - theoretical relation b-theta for n=6.cmr
337VD_Ski jumping 18 - theoretical relation b-theta for n=7.cmr

Animations

Activity 2.1.3 A: Faraday Experiment

Chapter
2. Electromagnetic induction
    2.1. Induced EMF in a moving conductor

Link to other SC family files
Online learning modules: Module Induction, Slide 9/17
Modelling experiment 2.1.3.M Faraday Experiment

Learning objectives
- To become familiar with the concepts of changing magnetic flux, induced (motional) emf and current associated with Faraday's Law of Induction.
- To investigate how the velocity of the conductor bar moving in a uniform magnetic field changes in time.

Applied ICT technology
Animation

Interaction
Look at the horseshoe magnet and draw a sketch of the magnetic field following conventions for the notation. Click "View Field Lines" to compare the magnetic field with your drawing. Click on the magnet top reverse the polarity.

Click and drag the velocity vector to move the wire loop with constant velocity into a homogenous magnetic field set up by the horseshoe magnet. Try this with different velocities.

Minds-On questions

- What relationship between the velocity and the magnitude of the induced current do you find?
- What do you think will happen if you move the loop around inside the magnetic field? (It is not possible to do this with the animation)
- Click on the magnet to flip it around when the loop is inside the magnetic field. Can you explain what you see?

Proposed Student Activities

Activity 1. Investigate how the sign of the induced current depends on the direction of the magnetic field (orientation of the magnet).

Activity 2. Investigate how the sign of the induced current depends on the direction of the moving wire loop.

Activity 3. Investigate how the magnitude of the induced current depends on the speed of the moving wire loop.

Activity 4. Based on activity 2 and 3, what can you say about the relationship between the sign and magnitude of the induced current and the velocity of the moving wire loop? Can you express this using vector notation?

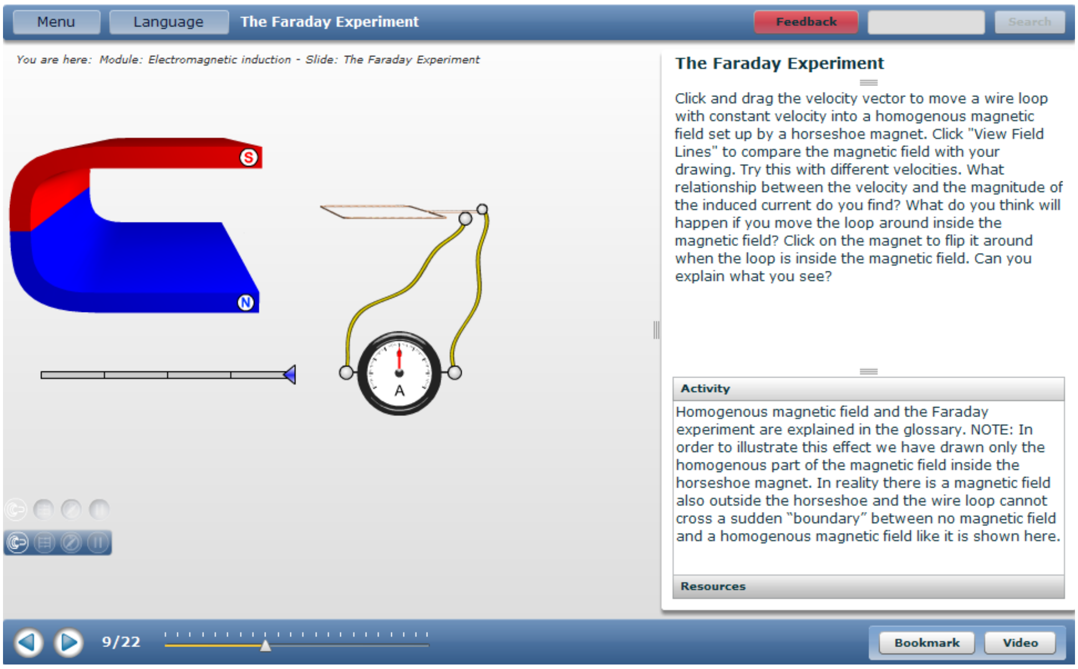


Figure 57. Animation of Faraday experiment

Note

The term "Homogenous magnetic field" and the Faraday experiment are explained in the glossary included in the SUPERCOMET Online Modules.

The conceptual nature of the animations is exemplified as only the homogenous part of the magnetic field inside the horseshoe magnet is shown. In reality there is a magnetic field also outside the horseshoe and therefore wire loop cannot cross a sudden "boundary" between no magnetic field and a homogenous magnetic field like it is shown here.

Evaluation

The MOSEM² 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 MOSEM² 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 medical and communication applications of technologies	Strongly agree	5	4	3	2	1	Strongly disagree
6. I am interested in the military applications of technologies	Strongly agree	5	4	3	2	1	Strongly disagree
ABOUT THE SIMULATIONS							
7. The simulations were interesting	Strongly agree	5	4	3	2	1	Strongly disagree
8. The simulations were difficult to carry out	Strongly agree	5	4	3	2	1	Strongly disagree
9. The simulations were useful	Strongly agree	5	4	3	2	1	Strongly disagree
10. There were no difficulties in carrying out the simulations	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 simulations.	Strongly agree	5	4	3	2	1	Strongly disagree
12. I took an active role during the simulations	Strongly agree	5	4	3	2	1	Strongly disagree
13. The students worked together on the simulations and discussed them	Strongly agree	5	4	3	2	1	Strongly disagree
GENERAL							
14. Which parts of the MOSEM² course did you particularly like? Please give reasons for your answer.							
15. Do you think that you have learned through the MOSEM² lessons?							

Please give reasons for your answer.
16. List two things that you thought were particularly good about the MOSEM² lessons: A B
17. List two things that you thought were not good about the MOSEM² lessons: A B
18. Would you recommend the MOSEM² lessons for the other pupils? Please give reasons for your answer.
19. What changes or improvements would you suggest for the MOSEM² lessons?
20. Are there any other comments that you wish to make about the MOSEM² lessons?

Interview form for teachers after classroom trials

Which models, simulations and animations were used?

Context

Question: Describe the school context in which you used the model or simulations.

Prompt questions to be used as necessary:

- Was the material suitable for your school context? Please explain.
- Was the material 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 material 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 materials might be appropriate to use alongside these?.

Experiment

Question: Describe how the simulation(s) or model(s) was/were carried out.

Prompt questions to be used as necessary:

- Was the simulation easy to carry out?
- Did the simulation work as you expected?
- Were there any difficulties in carrying out the simulation?
- Was the multimedia support easy to use?
- Do you have any suggestions as to how the simulation could be improved? Please explain.

Usefulness

Question: What had the students learned after their analysis of the experiment?

Prompt questions to be used as necessary:

- Which (phenomenological and/or conceptual) aspects were most frequent in the students' analysis of the simulation or model?
- Did the simulation or model 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 simulation or model, did students introduce questions, did students introduce interpretative elements?
- Did students take an active role during the learning episode? Please explain how.
- To what extent was it necessary to guide students in understanding the phenomenon?
- Did the exercise 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 teachers:							
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 MOSEM² 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. Simulations	Very useful	5	4	3	2	1	Not at all useful
21. Models	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 MOSEM² materials?

Thank you for your help

Evaluation report

The evaluation of the MOSEM² project was conducted using the questionnaire and interview data from school students, trainee teachers and practicing teachers.

School students

Gender split: 46% female, 54% male.
Average age: 17.5 years.
Age range: 16 to 18 years.

In summarising the data for questions 3 to 13, since ordinal data are being used, modal rather than mean values will be used:

Question	3	4	5	6	7	8	9	10	11	12	13
Modal value	4	4	4	3	4	2	4	4	3	2	4

The responses to items 3 to 6 show agreement with the statement regarding interest in science, interest in physics and in both medical and communication applications of technology, with a neutral response to military applications.. However some difference is observed between male and female students:

Question	3	4	5	6
Male mode	4	4	4	5
Female mode	4	4	5	3

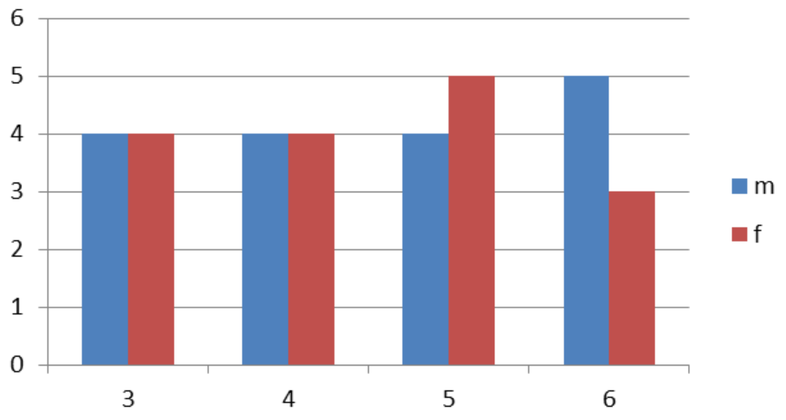


Figure 59. Modal values for items 3 to 6

A Chi-square analysis of these data returns a value of 0.67 with a critical value, with three degrees of freedom, of 6.25. Hence, at the 0.01 level, there is no significant difference between the male and female students.

Questions 7 through to 13 focus on the students' response to the simulations. It is worth noting that questions 8 and 11 are phrased in the negative:

Q8: The simulations were difficult to carry out;
Q11: I need a lot of help from the teacher to understand what was going on in the simulations.

Hence, with the exception of item 12 (the statement " I took an active role during the simulations"), the responses show students reacted positively to the simulations.

In exploring gender differences to the items we have:

Question	7	8	9	10	11	12	13
Male mode	4	2	4	4	3	2	4
Female mode	4	2	4	3	4	2	4

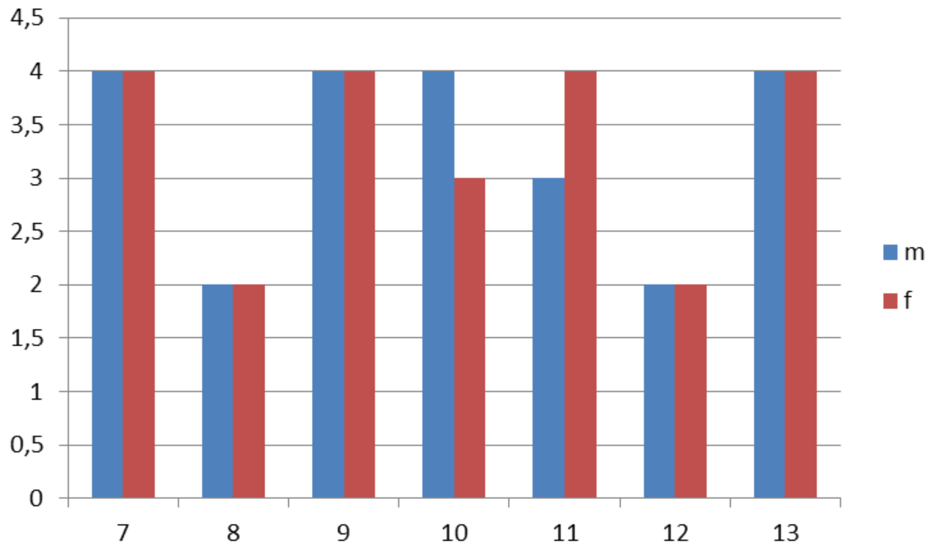


Figure 60. Modal values for items 7 to 13

A Chi-square analysis of these data returns a value of 0.99 with a critical value, with six degrees of freedom, of 6.25. Hence, at the 0.01 level, there is no significant difference between the male and female students.

Questions 14 through to 20 allowed for a narrative response which the project can use to both develop the materials and to triangulate findings from the questionnaire data.
Given the variety of cultural and educational contexts in which data are collected on such a programme a number of common themes can be extracted and these are reported here:

Q14 Which parts of the MOSEM² course did you particularly like?
Falling magnets in a copper tube
Magnet slalom
The homopolar motor
The simplicity of the computer interface

Q15 Do you think that you have learned through the MOSEM² lessons?
Yes, 'seeing' experiments that are not in the text books
Yes, better understanding of theory after seeing the effects
Yes, more physics learned/understood

Q16 List two things that you thought were particularly good about the MOSEM² lessons
Interesting material
Easy to use
Practical nature

Q17 List two things that you thought good about the MOSEM² lessons
Mostly this was – none
Lack of time to further explore the interesting effects

Q18 Would you recommend the MOSEM² lessons for the other pupils?
Yes, helps understanding
Yes, very interesting

Q19 What changes or improvements would you suggest for the MOSEM² lessons?
Give a longer time
Have more apparatus, especially for larger groups

Q20 Are there any other comments that you wish to make about MOSEM² lessons?
This was invariably left blank for simply restated the about comments. However one Polish student responded; "I would like to do it every school day."

Teacher Seminar

Number of years teaching: 0 to 10 years, 0%; 10 to 20 years, 57%; 20 to 30 years, 21%; over 30 years 22%
First degree in physics: 71%

Questions 3 through to 6 replicate those on the student questionnaire and address *interest* the modal values for these data are reported below:

Question	3	4	5	6
Modal value	5	5	5	3

Questions 7 through to 17 address the *teacher seminar and its materials.* The modal values are reported below:

Q	7	8	9	10	11	12	13	14	15	16	17
Mode	5	1	5	5	5	5	5	5	5	5	5

These data show very strong agreement with the intended outcomes of the seminar. Question 8 is negatively phrased, asking if the seminar was *not suitable for my level of skill.* Teachers attending, whilst being self-selecting, obviously felt the seminar met their expectations.

Questions 18 through to 21 consider the usefulness of the materials for teaching. Again the modal values are reported below:

Question	18	19	20	21
Modal value	4	5	5	5

Questions 22 through to 25 address the *organisation* of the teacher seminar:

Question	22	23	24	25
Modal value	5	4	5	5

Question 26 was a narrative box but the only response was of the form, *everything is very useful.*

Trainee Teachers

The trainee teachers in the study were all following a one year Post Graduate Certificate in Education [PGCE, the major route into science teaching in the UK]. The research instrument used was that from the teacher seminar and all trainee teachers followed a one day seminar covering all the materials.

Degree background:
Biology: 14%, chemistry: 43%, physics: 43%

Gender split:
Female: 45%, male 55%

The modal, contrasted with those of experienced teachers, are given below:

Question	3	4	5	6
Modal value teachers	5	5	5	3
Modal value trainees	5	5	5	4

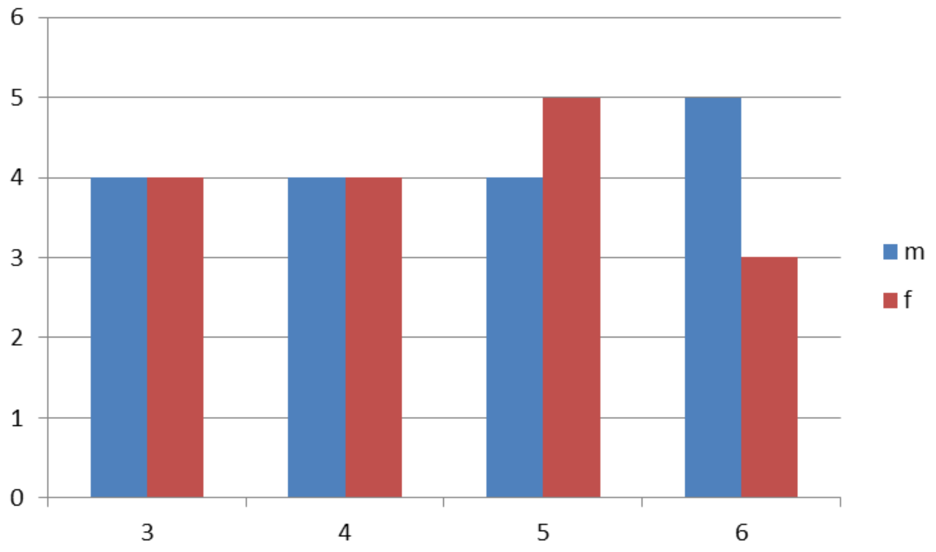


Figure 61. Modal values for items 3 to 6

Q	7	8	9	10	11	12	13	14	15	16	17
Modal value teachers	5	1	5	5	5	5	5	5	5	5	5
Modal value trainees	5	2	5	5	5	5	5	5	5	5	5

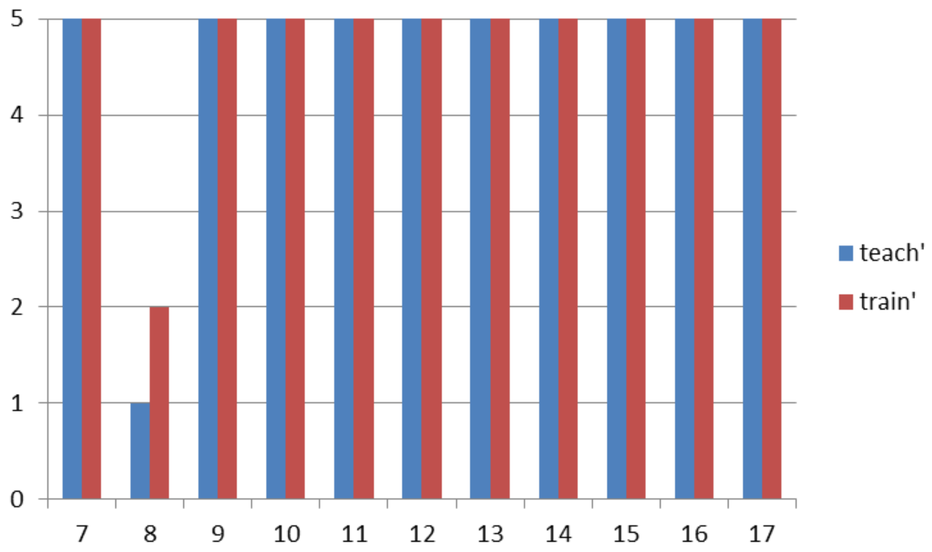


Figure 62. Modal values for items 7 to 17

Question	18	19	20	21
Modal value teachers	4	5	5	5
Modal value trainees	5	5	5	5

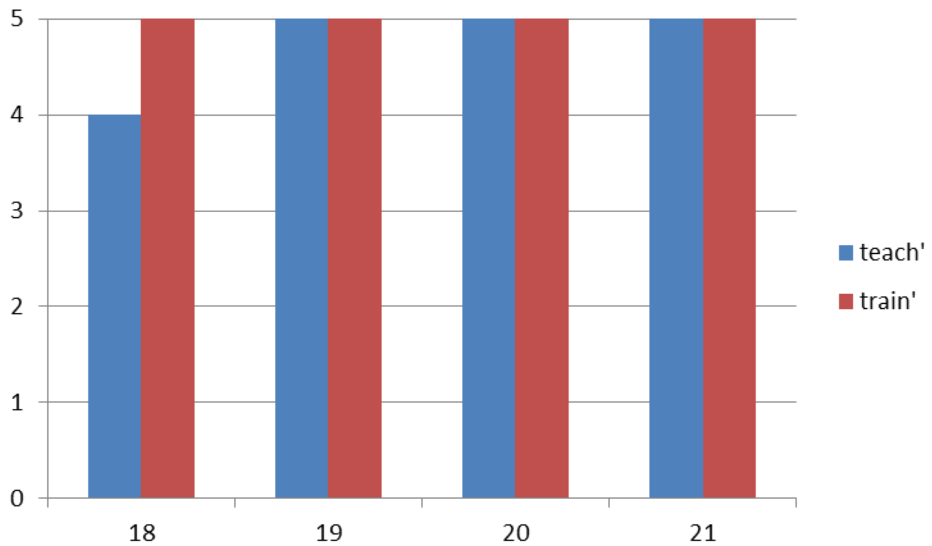


Figure 63. Modal values for items 18 to 21

Question	22	23	24	25
Modal value teachers	5	4	5	5
Modal value trainees	5	5	5	5

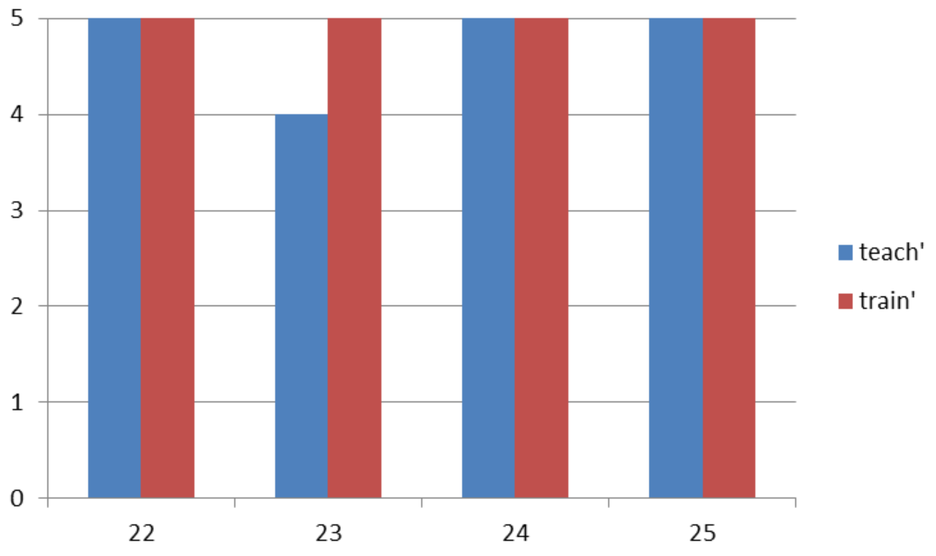


Figure 64. Modal values for items 22 to 25

These data show, visually, the agreement between experienced and trainee teachers when using the MOSEM² materials.

In summary

In light of these data the project can feel confident that school students, trainee teachers and experienced teachers are very positive towards the MOSEM² materials and the teacher seminar.

It is also worthy of note that the data show agreement between male and female students and, amongst teachers, those with a physics degree and those not.

Valorisation

Activities

The MOSEM² activities, studies, materials and teacher seminar formats are widely spread in a lot of countries. Looking at the efforts[19] made by the partners, it is safe to say that – without going into details – MOSEM² has been brought to hundreds of teachers in more than 10 countries all over Europe and even the world, with special efforts in the participating countries like Italy, Poland, Norway, Bulgaria, Belgium and Spain.

Not only teachers but also researchers, decision makers and other key persons in the field of physics education were informed. This has been done by attending local, national and international conferences like CBLiS, GIREP and MPTL. Workshops for participants and presentations attracted hundreds of interested people. On the local field both research and workshops were guided by the local partners, studying the effects of the MOSEM² approaches and training teachers in the advanced fields of simulations, modeling and video measurement.

During this project new internet technologies for valorisation were incorporated, the most successful one being the films on YouTube, with tens of thousands of hits. We expect more long-term results from social networks.

It is good to remind the reader of the fact that most MOSEM² deliverables are free for use in educational settings, provided the source is mentioned. In this way valorisation of MOSEM² will go on, long after the administrative end of the project.

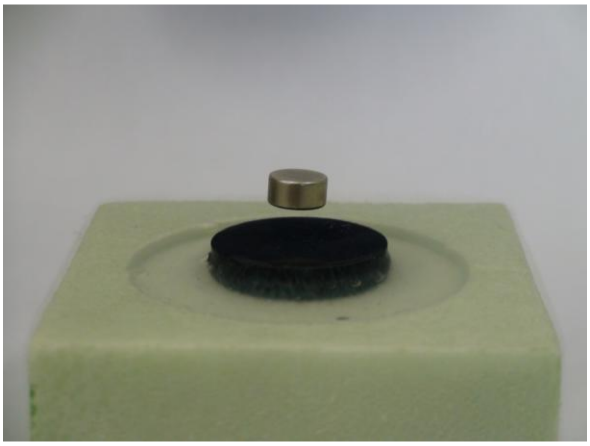
Online resources

Results:	**mosem.eu**
Videos:	youtube.mosem.eu
Simulations:	simulations.mosem.eu
Animations:	animations.mosem.eu
	online.supercomet.eu
Discuss:	**forum.mosem.eu**
News:	witter.mosem.eu
Network:	linkedin.mosem.eu
Updates:	facebook.mosem.eu
Archive:	media.mosem.eu
Homepage:	supercomet.eu
GIREP:	girep.org
MPTL:	mptl.eu/index.htm
CBLIS:	cblis2010.waw.pl

[19] The final report shows a list of nearly 100 actions undertaken by all partners together

Explaining superconductivity

A levitating magnet, just floating in the air… Below is a dark pellet, immersed in a transparent boiling liquid producing some white fumes. An electrical current, running along a loop without ever vanishing…



It is no magic, just physics: superconductivity more precisely. It is easy to find some pictures and movies on the internet, but much more difficult to find a convincing and scientifically correct explanation.

The reason for this is that it all boils down to quantum mechanics. It is true that you should go back to quantum mechanics to give a proper explanation of almost everything (from the colour of gems to the TV remote control, from the urban neon lights to the stability of chemical molecules), but superconductivity is so far from our day-to-day experiences and knowledge that it is very difficult to comprehend. We do not aim to give a full lesson on superconductivity here, only to present some ideas in order to understand these experiments.

Historic notes

Temperature

It is easy to heat up matter; just put in a fire or in the middle of an atomic explosion if you can. Cooling it down is much more difficult. Understanding and producing low temperatures was one of the challenges for the late 19th century physicists.

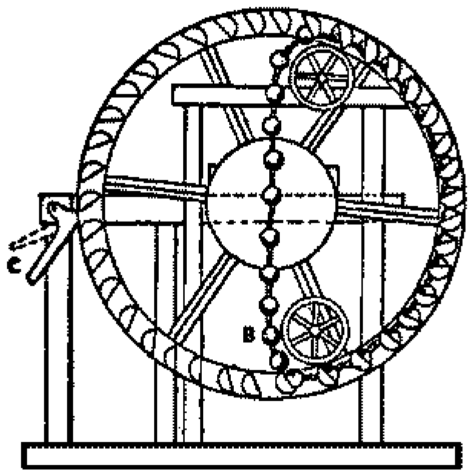
The understanding part has led to a new branch of physics, “thermodynamics”: it explores the ways heat can be exchanged; when it is allowed and when it is not. If you burn yourself when touching a hot pan (that is, if heat goes from the pan to your hand and not the other way), blame it on thermodynamics.

A great achievement of thermodynamics is the introduction of a strange quantity, “energy”, to describe heat as “thermal energy”. The concept of energy is so universal that it can be applied to every other branch of physics (chemical energy, electrical energy, electromagnetic energy, mechanical kinetic energy, atomic energy, various forms of potential energy, etc). Energy cannot disappear nor be created, but it can be converted from one of its forms to another.

In such an energy conversion, some of the energy is converted to a different form than intended, usually thermal energy. Mechanical energy is converted to thermal energy through friction, and electrical energy is converted to heat through resistance. Heat itself is impossible to keep in one place; it always radiates and/or dissipates to the surroundings. Energy cannot disappear, but we often call this phenomenon “heat loss”.

Perpetual machines are ruled out by this theory. It is theorized that even black holes, attracting everything including light, slowly give off energy to their surroundings through something called “Hawking radiation”. This is another example of quantum physics which would not have been possible without the concept of thermodynamics.

Conventional motors convert chemical energy first to heat energy which leads to potential energy stored as high pressure which again is converted to mechanical energy. Such motors become very warm because of the way they operate (with high temperatures inside) and because of friction between their moving parts. The heat loss does not contribute to the purpose of the motor, which is to provide mechanical energy for a machine (e.g. a rocket, a car, a compressor or an electrical generator).



This perpetual machine[20] was patented in the mid-19th century. It is supposed to work by converting between kinetic and potential mechanical energy, but due to friction and heat loss it will stop. Also, since it does not produce any extra energy, even if it was without friction it could not be used for anything except turning around by itself.

Electrical motors convert electrical energy directly to mechanical energy, and plasma (fluorescent) lamps or tubes convert electrical energy directly to light. Both give off heat because of the resistance in their electrical wires. An extreme example of resistance leading to heat is conventional light bulbs – they become so hot that they start glowing, and give off light. However, like other (incandescent) materials glowing because of their high temperature (e.g. the particles in the flame of a burning candle), light bulbs give off a lot more heat than light.

Another great achievement of thermodynamics is that at last it gives a precise definition of what “temperature” is. Everybody knows what temperature is of course, but if you ask “What *precisely* is temperature?” nobody will find it an easy question to answer. Thermodynamics define temperature as the energy stockpiled in a system by the random and microscopic movements of the constituent of this system (atoms, molecules …): this is what is called “thermal agitation”, or “thermal energy”.

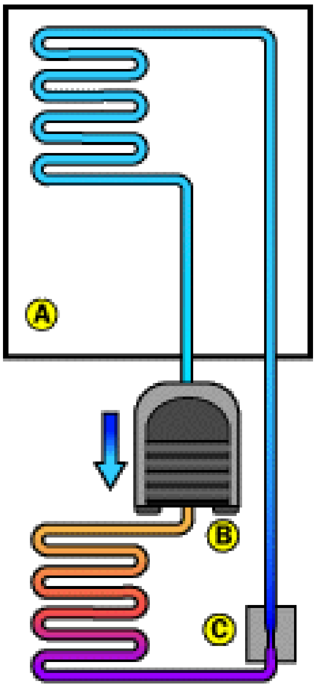
[20] Credits: Donald Simanek's Pages http://www.lhup.edu/~dsimanek/museum/unwork.htm

This definition has two immediate consequences of importance. Firstly, you need matter to have a temperature to speak of. You cannot define a temperature in absolute vacuum. Therefore we try to make vacuums for insulation – in order to stop heat flows from one place to another. Since air is much closer to a vacuum than most other regular substances, pockets or layers of air are very efficient for insulation. Clothes, wall insulation and double windows in houses all use the same principle of keeping air inside to reduce the heat flow.

Secondly, there is a limiting temperature below which you cannot go, the temperature that corresponds to zero thermal agitation. This limiting temperature is called “absolute zero”, and the physicists use this temperature as the starting point of their temperature scale, the Kelvin scale.

The cold

Allowing a deep understanding of energy, thermodynamics opened the way to machines that produce coldness; machines that can take out thermal energy from a body and either convert it in something else or give it to another body. The second type of machines is called “heat pumps”. A fridge is a kind of heat pump; using electrical energy (the fridge must be plugged) it takes thermal energy from your food and releases it in your kitchen.



Thermodynamic cycle of a refrigerator[21].

1. The compressor (B) compresses the ammonia gas. The compressed gas heats up as it is pressurized (orange).
2. The coils on the back of the refrigerator let the hot ammonia gas dissipate its heat. The ammonia gas condenses into ammonia liquid (dark blue) at high pressure.
3. The high-pressure ammonia liquid flows through the expansion valve (C).

You can think of the expansion valve as a small hole. On one side of the hole is high-pressure ammonia liquid. On the other side of the hole is a low-pressure area (because the compressor is sucking gas out of that side).

4. The liquid ammonia immediately boils and vaporizes (light blue), its temperature dropping to -33°C. This makes the inside of the refrigerator (A) cold.

5. The cold ammonia gas is sucked up by the compressor, and the cycle repeats.

[21] From http://home.howstuffworks.com

The kitchen is heated more than the food is cooled, due to heat loss when converting the electrical energy to pressure in the compressor. Just as prescribed by the second law of thermodynamics, the heating and cooling do not cancel out. Heat pumps and air conditioners can do the same for an entire building. The heat loss at the pump/compressor is often referred to as the “efficiency” of the heat exchanger, and it varies with temperature. It is easier to cool your house in the winter and to heat it in the summer. The warmer it is outside, the more electrical energy you need in order to cool the inside air. And vice versa for warming when it is cold outside. Thermodynamics allows the design and optimization of this cycle.

For the physicists of the early 20th century, the appearance of low temperatures opens a new field to explore. How are the laws of physics affected when the temperature is lowered as close as possible from the absolute zero? Unfortunately, the closer you get to the absolute zero, the more difficult it is to get closer. Thus “cryogenics”, the art of reaching very low temperatures, was born.

One of the difficulties associated with the low temperature is that all gases become liquid or solid below a certain temperature. On the other hand, once you have succeeded in liquefying a gas, its temperature will remain below or at that liquefaction temperature. For instance, water will remain at 100ºC even when it is boiling (as long as the pressure does not change). Thus, an easy way to cool an object is to dip it in a bath of liquefied gas (a bain-marie in kitchen talk).

Obtaining the lowest temperature became a scientific competition among physicists at the end of the 19th century. At the turn of the century, one gas in particular remained a challenge – helium. Because of the few interactions between its atoms, this noble gas has a very low liquefying temperature. Succeeding in producing liquid helium was technically very difficult.

Heike Kamerlingh Onnes at the University of Leiden in Holland rose to the challenge. Professor Onnes organized a lab around his project to obtain liquid helium, obtaining funding and manpower dedicated to this problem. In 1908 his team finally succeeded in obtaining liquid helium, after several years of planning with the best specialists of the different techniques.


Heike Kamerlingh Onnes[22]

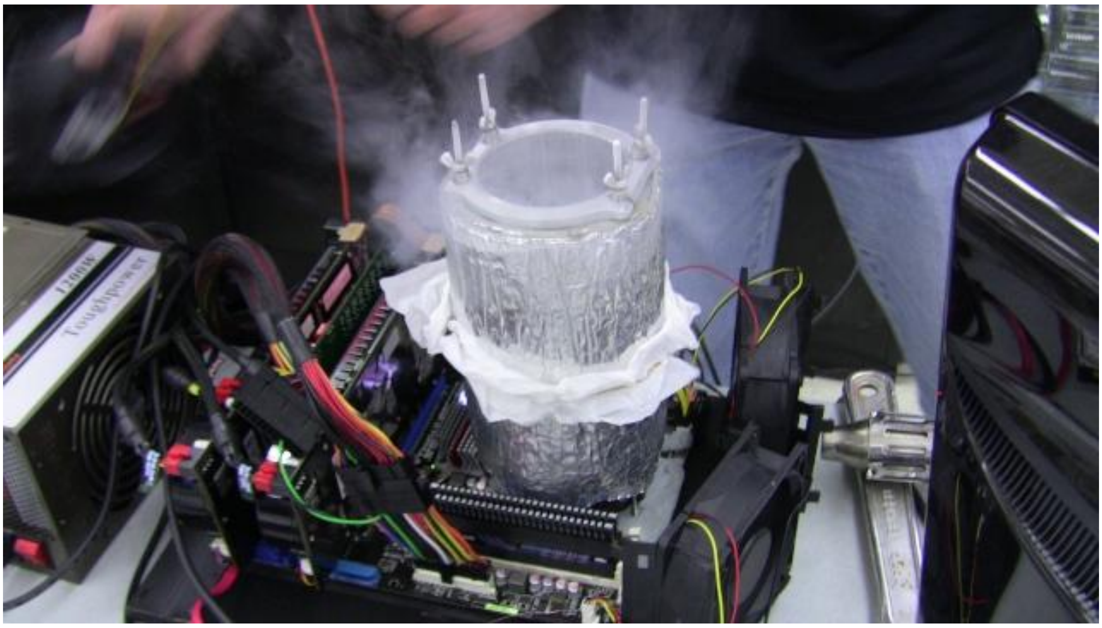
Liquid helium, boiling at only 4,2 K above the absolute zero under ambient pressure (and around 1,2 K when the pressure is reduced) opened the road to very low temperature physics. For years, Leiden was the only place in the world where such low

[22] Photo credits: http://nobelprize.org

temperatures could be obtained. One could even say the only place in the universe, since the “background thermal temperature” of the universe is 2,7 K – it is still cooling down from the Big Bang (this was only discovered much later).

For Onnes, it was only the beginning. He could now begin a systematic study of the properties of matter at such low temperatures. Other scientific centres also tried to reach these temperatures, and little by little cryogenic centres were built in various countries.

Nowadays, liquid helium can be purchased from companies producing liquefied gases, but is quite expensive and difficult to manipulate, so only specialists who really need it use it. The technology has also evolved, and some “cryogenic refrigerator machines” are used to reach temperatures much below that of liquid helium. In research labs, matter can now be cooled down to 0,000001 K (1 μK) or even much lower, but under these conditions the notion of “temperature” has to be used with care.



Liquid helium cools an AMD Phenom II quad core CPU overclocked to 6,93 GHz[23]

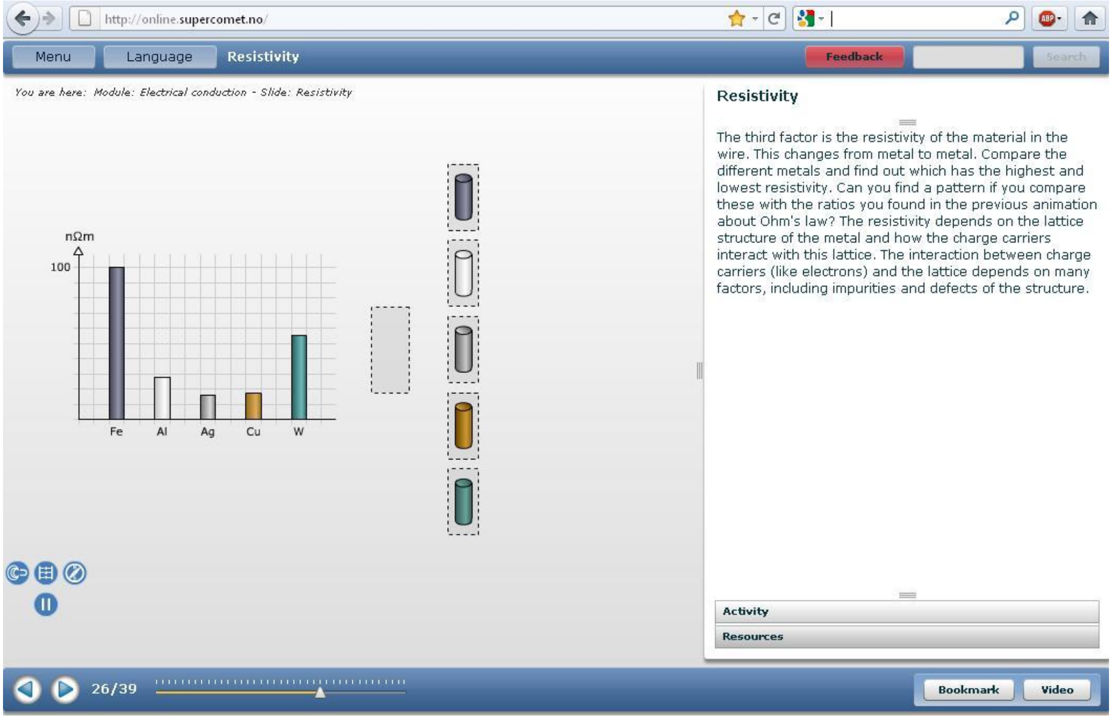
[23] Photo credits: http://www.wired.com/gadgetlab/2009/06/overclocked-amd-processor

Ohm’s law

One of the fundamental properties Onnes was interested in investigating was the electrical resistivity *R* that we all know from Ohm’s law:

$$U = R\,I$$

When an electrical current *I* flows through a metal, a differential of potential *U* appears and is proportional to *I*. The proportional coefficient, *R*, shows that something is resisting the flow of the current, and it varies between different metals.



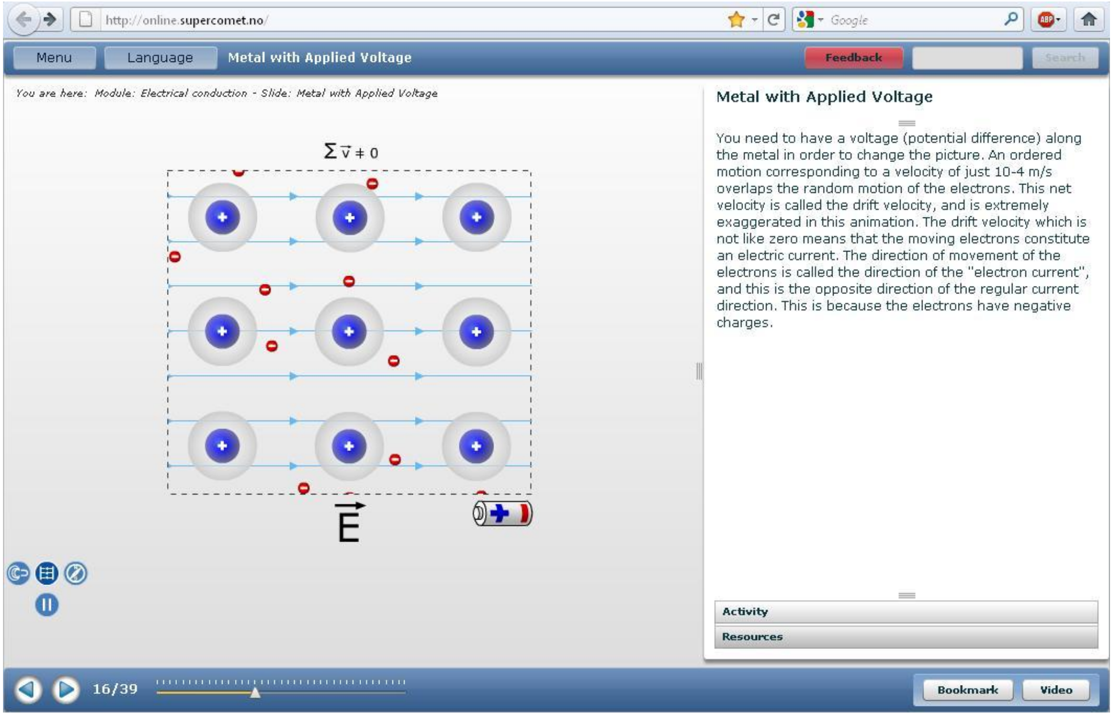
This resistance dissipates some energy (electrical energy is transformed into thermal energy: heat). This Joule effect is used in an electrical kettle to boil tea, and also explain the heat losses mentioned earlier in light bulbs, heat pumps etc.

The consequences of Ohm’s law are well known, and make good exams. But the real question is “Why?”

Why does a voltage appear? We now know that the electrical current corresponds to a flow of electrons in the metal, but what causes the resistance to the electrons in a metal? This fundamental question was one that Onnes wanted to tackle. His approach was to gather as much hard evidence as possible, and then see how they could be explained. His emphasis was on obtaining as good experimental data as possible, and he began a systematic study of electrical resistivity of metals of high purity, down to the lowest temperature available to him.

A distinctive property of a metal is that atoms in the bulk material let go of a few of their electrons. These “free” electrons are no longer bound to the atoms and can move freely within the metal. Free electrons constitute the electrical current; this is why metals are good conductors. Since the metal atoms are missing some electrons they are called ions and carry a positive charge counterbalancing the negative charge of the free electrons, so that a piece of metal remains globally neutral.

The classical idea was that hits between electrons (light, mobile) and metallic ions (much heavier, immobile) caused this resistance to the flow of electrons.

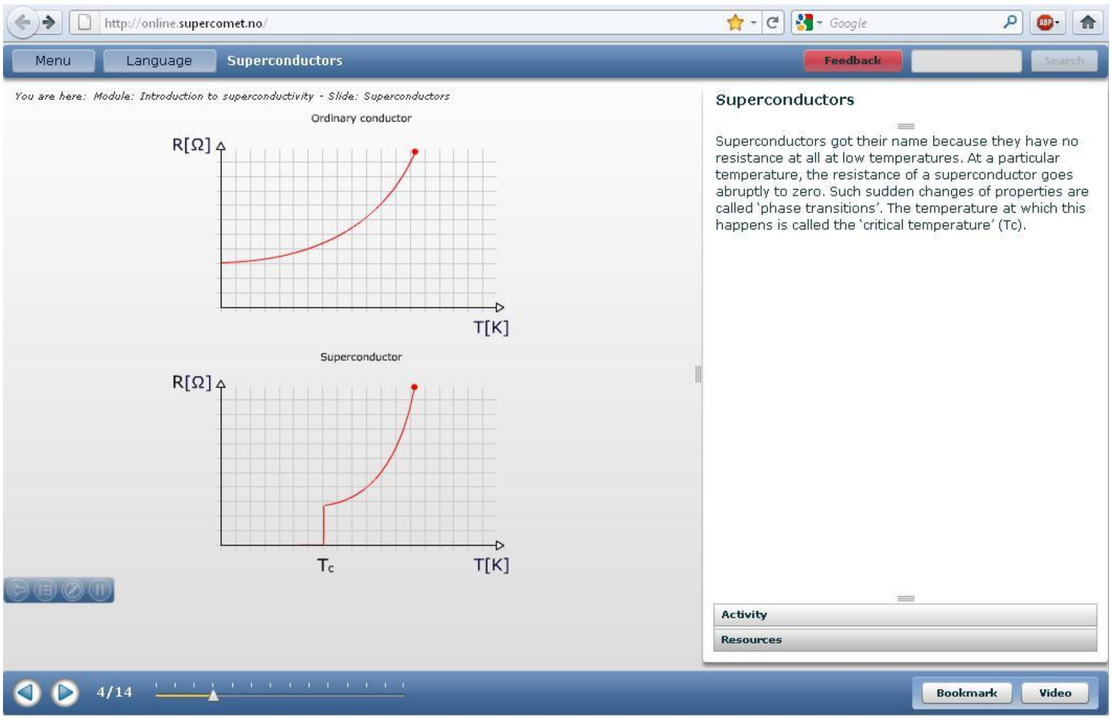


But although this theory could account for some of the properties of metals, some experimental facts were not explained, such as the sign of the Hall effect in some metals, or the dependence of resistivity on temperature. The fact was that the electron was newly discovered particle at the beginning of the century, and its properties were still a subject of debate.

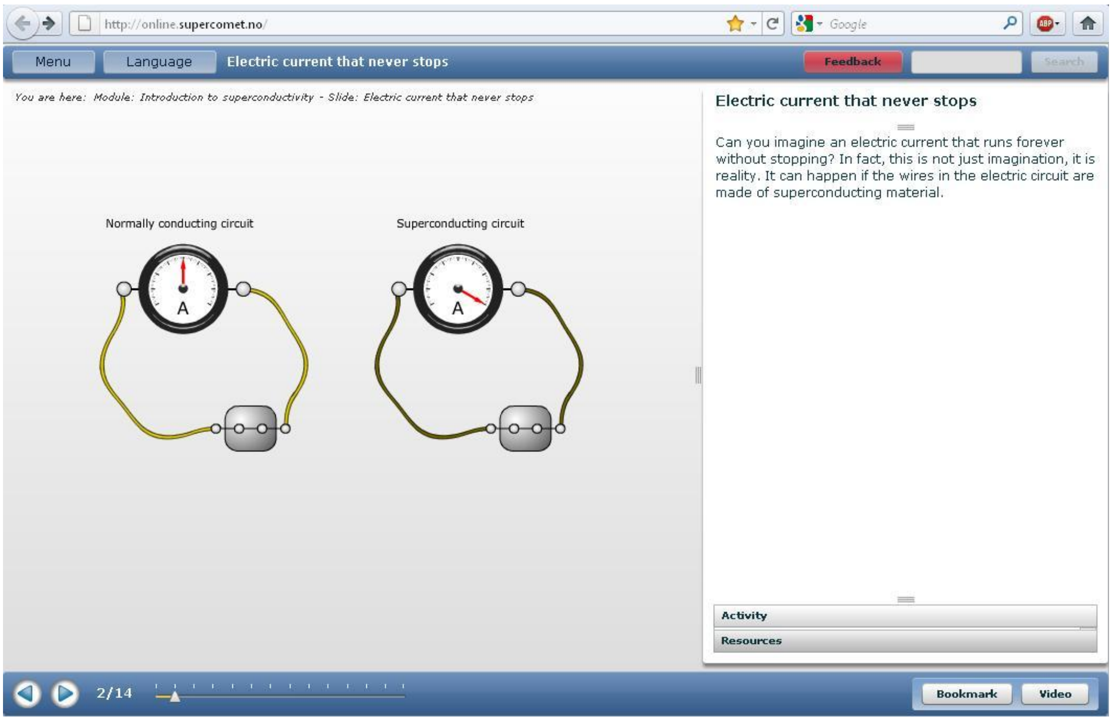
Onnes wanted to elucidate the properties of metals at low temperature. The value of the resistance in a metal was decreasing when the temperature was lowered: would the resistance always go down with temperature, and reach zero value at the absolute zero, or would the electrons become less mobile at very low temperature, which should then produce a huge increase of the electrical resistivity?

The first measurements showed that for a metal, the resistance was always decreasing as the temperature was lowered, but that it tended to saturate toward a limiting value instead of vanishing. Since this limiting value of the electrical resistance was depending a lot on the purity of the sample that was studied, the purity of the metal appeared as a critical factor (different copper samples will saturate at different values -- bending a sample could change this value!). One of the metals that could be most easily purified was mercury, since it is liquid at ambient temperature, and became the object of studies in Leiden in 1911.

Incredibly, below 4,2 K, the resistance of mercury suddenly dropped to zero.



This phenomenon was reproducible, very sharp, and unexplained. Suddenly, it seemed that the electrons can move in the metal without anything to restrain them. More surprising, the value is a real zero, (at the precision of the measurement), which is quite rare in physics. Confronted with a new and unexpected phenomenon, Heike Kamerlingh Onnes did what any good physicist would have done: he gave it a name, “superconductivity”. He received the Nobel prize in physics for his discovery two years later.



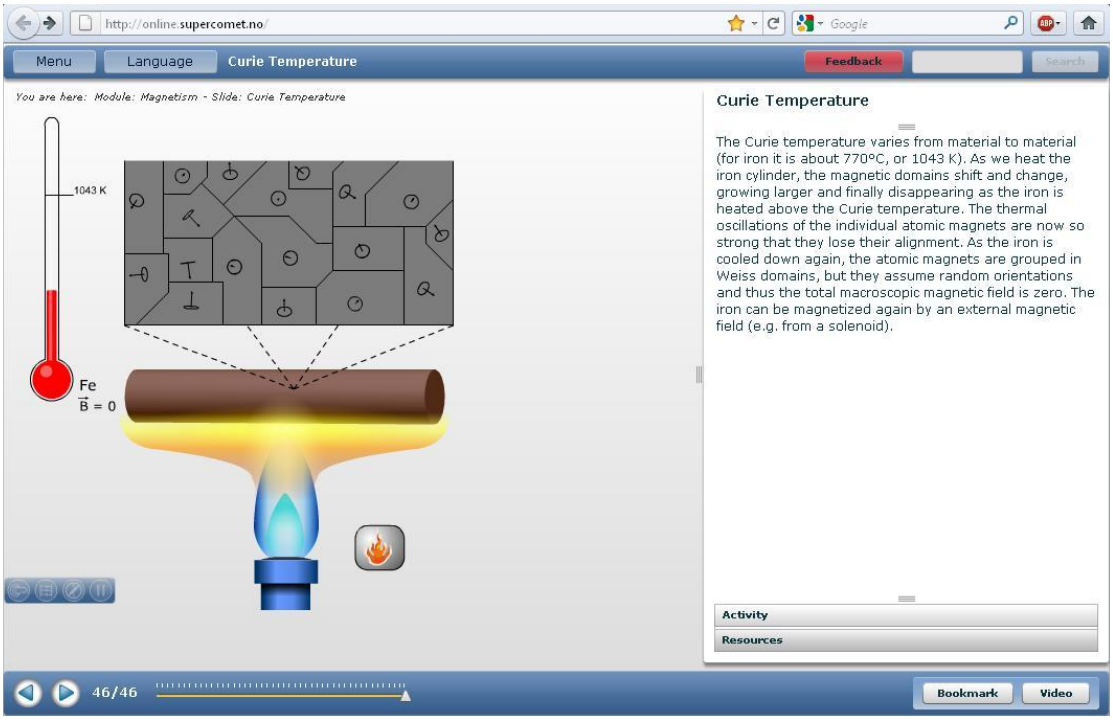
To demonstrate the total disappearance of any resistance to the flow of the electrical current, Onnes sent a current in a closed circuit (a ring) made of a superconducting material, and then stopped the current source. If a resistance, however small, still existed, the current circulating within the ring should have vanished very quickly due to the braking of the electrons.

But what was observed experimentally was that, left alone, the electrical current kept flowing around the ring, infinitely (this property is now used to allow hospital MRI scanners to work). Note that this is not a perpetual motion machine – the kind of machines that thermodynamic banishes – since there is no creation of energy. The electrical energy is just stored in the superconducting ring (and can be recovered).

Qualitative explanation

The explanation of superconductivity is deeply rooted in the quantum nature of the electrons; thus any kind of easy explanation or description is an oversimplification (a lie, in other words). We will try to give here the main ideas. Some references are given for those who want to go further.

The main idea to understand, or to accept, is that the electrons behave differently above and below the “critical temperature” for superconductivity to occur, T_c. Thermodynamic theory states that any system will have a preferred status at a given temperature (and any given pressure, and given magnetic field, and any given relevant parameter). Indeed, thermodynamics introduce a kind of “status energy”, and the system will naturally go into the preferred configuration, that with the lowest “status energy”.



A classical example is the vaporization of water: when working under atmospheric pressure the preferred configuration of water molecules is gas above 100°C, and below 100°C it is liquid. This is how thermodynamics explain the vaporization of any liquid, but this kind of description (called "phase transition") has a much wider application in physics. For example, a magnet that is heated up above a characteristic temperature (the Curie temperature), will lose its ferromagnetic properties. Gadolinium is a ferromagnet below 19°C, but above 19°C it isn't any more, because the preferred configuration changes at that temperature.

Similarly, above T_c the electrons' preferred configuration is normal metallic individual electrons. But below T_c their preferred configuration is superconducting electron pairs.

The thermodynamic approach was lead by two Soviet physicists, Vitaly Lazarevich Ginzburg and Lev Landau, and their names are now linked to this approach. Of course it is much more powerful than the naïve picture presented here. They postulated, by analogy with the quantum mechanics (but without hard evidence), the way the energy should depend on the magnetic field and introduced their ideas in equations. The results were impressive: without going into what superconductivity is they could explain all the known properties of superconductors and make some predictions that would be proven right soon after (the existence of vortices for example). It was the first working tool that correctly described superconductivity; the Ginzburg-Landau theory is still used today.

The thermodynamic approach is thus successful to describe the superconducting states (the "why?"), but it does not address the question of the superconducting configuration (the "what").

Truth to tell, neither do thermodynamics address the question of what is a metallic electron… The question "why $U = R\ I$ " can only be answered if the precise nature of the electrons is understood. The classical description of an electron as a small marble with an electrical charge gives a picture of the current flow (a flow of particles, a bit like a river) but fails to describe correctly the properties of metals. A great achievement of quantum physics is to have succeeded in doing so.

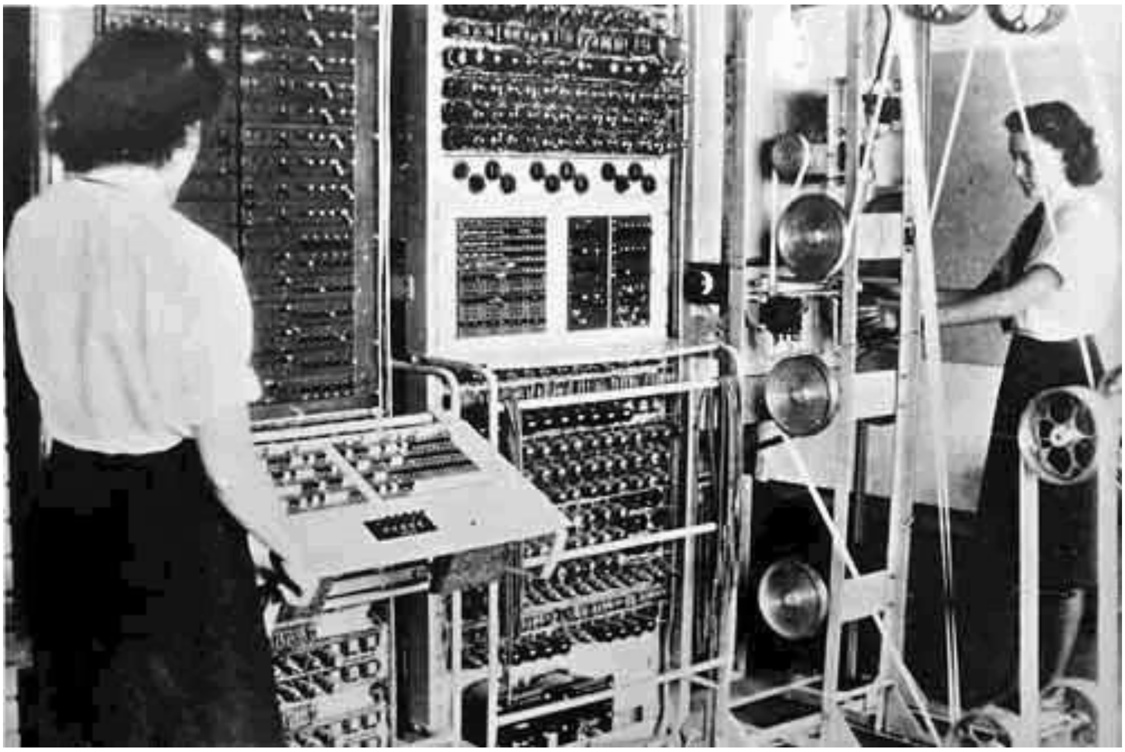
Quantum mechanics

Quantum physics has the reputation of being very difficult to understand, and full of paradoxes. While it is true that its formalism is heavily mathematically oriented, it is important to realize that quantum physics has deep implications in everyday life – even if one does not realize it – and that the so-called "paradoxes" are just the consequences of this theory that seems to defy our common sense, but only because the latter is based on a classical approach of reality. Quantum physics is a very coherent theory that describes perfectly well all the experiments' results and that was never proven wrong, however hard it was tried – and it was tried very hard.

Einstein was famous for not liking some of the assumptions of this theory: in his mind quantum physics was imperfect and some deeper theory was still to be found. However, in the early 80's, Alain Aspect succeeded in realizing a real experiment[24] that demonstrated that Einstein strongest argument was not valid.

It does not mean that quantum physics theory will never evolve, but so far this theory as it is describes perfectly the world as it is: Quantum physics never failed us yet. And that is well, since it flows all around us. For example, the laser or the silicon electronics rely deeply on quantum effects in their working principles, and they could be invented only after a clear understanding of these effects.

Any processor chip or optical telecom device is directly a child of the curiosity of pioneers who tried to comprehend what matter really is. Listening to an ipod is listening to quantum physics. Without the quantum description of what an electron is, we would still use lamp tubes as transistors, and a “computer” would be a room full of huge electronic racks with lamp acting as transistors.



The Colossus Mark 2 computer at Bletchley Park[25].

The construction of quantum physics took several decades; here we will just present the basic hypothesis. There is much more in quantum physics of course, and a small bibliography is proposed at the end of this guide for further reading.

Quantum physics relies on several hypotheses that are out of the classical scope:

- the energy of any system is quantified;

[24] See for instance http://en.wikipedia.org/wiki/Alain_Aspect
[25] Photo credits: http://en.wikipedia.org/wiki/File:Colossus.jpg

- it is impossible to know precisely both the position and the speed of a quantum object;
- a quantum object is dual, both a wave and a particle.

The energy of a system is quantified

In classical thermodynamics, energy is a quantity that can not be created nor destroyed, only exchanged or transformed following few ruling principles. There is no limit as to how small the quantity of energy involved can be. Why should it be? Matter however behaves differently: there is a quantity of energy, very small but different from zero, which is the token of energy: any exchange or transformation of energy must be a round number of these tokens.

Of course the energies that are part of our everyday life are so large compared to this token that we can not feel the granularity of energy, but for a particle it has strong implications. The stability of an atom for example is only possible because its electrons can only exist at fixed values of energies around the nucleus: this is the basis of modern chemistry. The classical description that allows the electrons to be as near as the nucleus as possible predicts the collapse of all the electrons, attracted by the nucleus: the universe would be annihilated in milliseconds (bless quantum physics).

The uncertainty principle

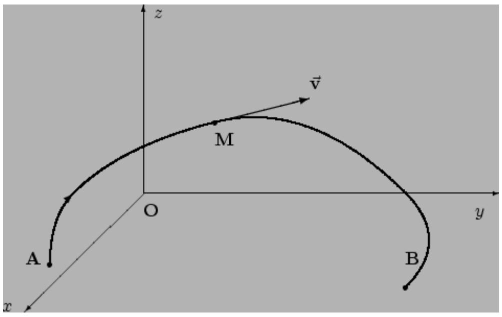
First postulated by Heisenberg, this principle states that it is not possible to know at the same time the speed and the position of a particle with an infinite precision: there must be a minimum of uncertainty in these values if one tries to measure them. This minimum of uncertainty is related to the quantification of energy, and directly related to the true nature of a quantum particle (wave-particle duality). It is only baffling because our mind wants a particle to belike a marble, a small hard sphere of matter – which it is not.

Note that the name “uncertainty principle” is somewhat misleading: it does not mean that quantum physics is not certain, nor does it means that it is not a precise theory. Quantum physics is very precise in its predictions (and so far they have all been proven right), but it describes matter in a way that we are not used to.

Wave-particle duality

One of the important revolutions of quantum physics lies in the description of matter. The notion of particle as a tiny marble (with a mass, a precise position in space and a velocity) is replaced by the notion of “wave-particle duality”. In classical physics (and everyday life), we can make a clear distinction between a particle (say a tennis ball) and a wave (for example a sound wave).

In classical physics, a particle has a position, a velocity and a trajectory, whereas a wave has a frequency (or a “phase”, related to its wavelength), and a direction of propagation. When two particles meet, they collide. When two waves meet, they superpose and interfere: if the crests of the two waves arrive at the same time at the same position, they will build up a larger wave at that point.



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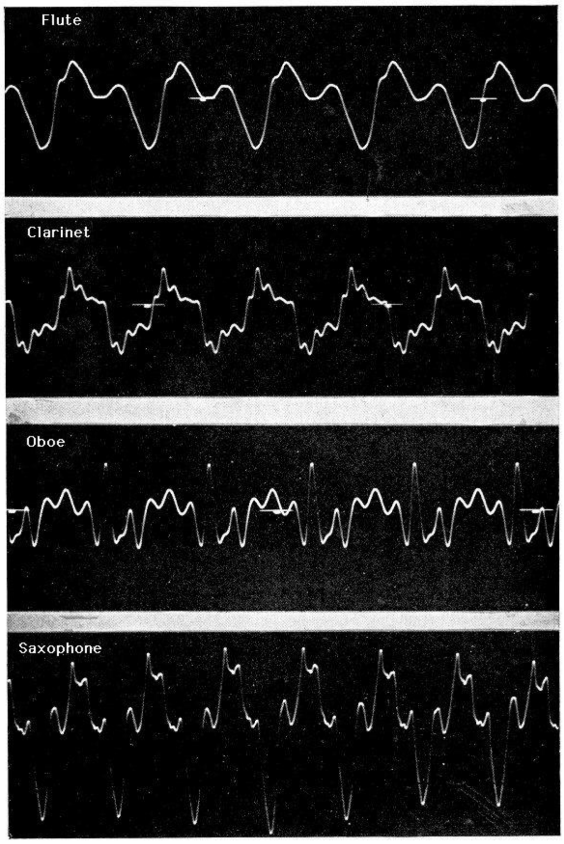
A tennis ball, with a position, a velocity and a trajectory, is a classical particle.



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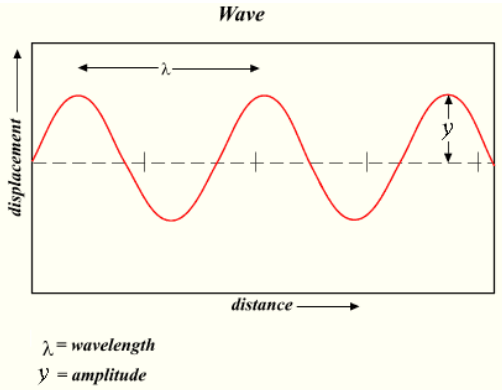
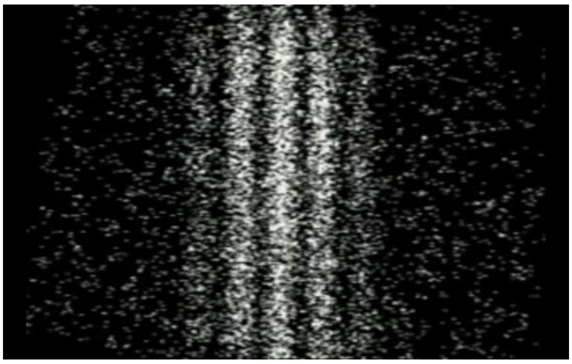


A sound wave (here picked from a microphone), with a wavelength and an amplitude, is a classical wave.

On the contrary, if the crest of a wave arrives at the same time as the pit of the second wave, they will cancel each other out (this is how noise suppression headsets work: they send the sound wave in the ear that will cancel out the surrounding noise).

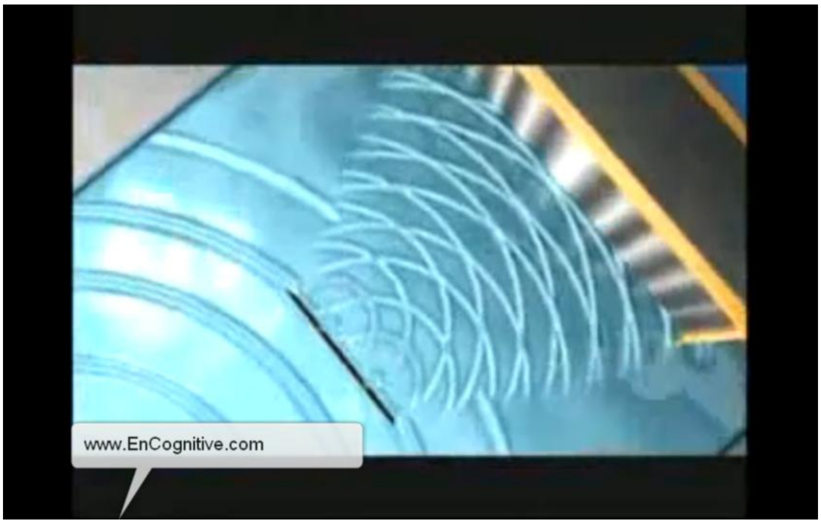
However, quantum physics forces us to reconsider these notions. Experiences demonstrated that particles do not behave as a classical particle would; some of their properties are wave-like. Consider an electron: it has a mass and a charge – it can easily be pictured as a small marble. But it was experimentally demonstrated that electrons can produce interference patterns; something no classical particle can do – it is a characteristic property of waves.

In a famous experiment done by the Hitachi team[26], single electrons were sent one by one through an appropriate system (equivalent to the Young slit experiment for light).


Hitachi group interference pattern

The resulting interference pattern demonstrated the “wave-like” nature of the electrons. In this experiment, each electron interferes only with itself, since they were sent one by one… It is impossible to understand this experiment, and many others, without considering that the electron possesses some properties of a wave.

Quantum mechanics resolves the situation by considering each quantum object as a “wave function”, a quantum wave that can mimic either the properties of a classical particle in some situation, or that of a wave in other situation. The quantum theory gives a full set of mathematical laws for handling these objects; it does not say why it is so, but reality seems to follow these rules.



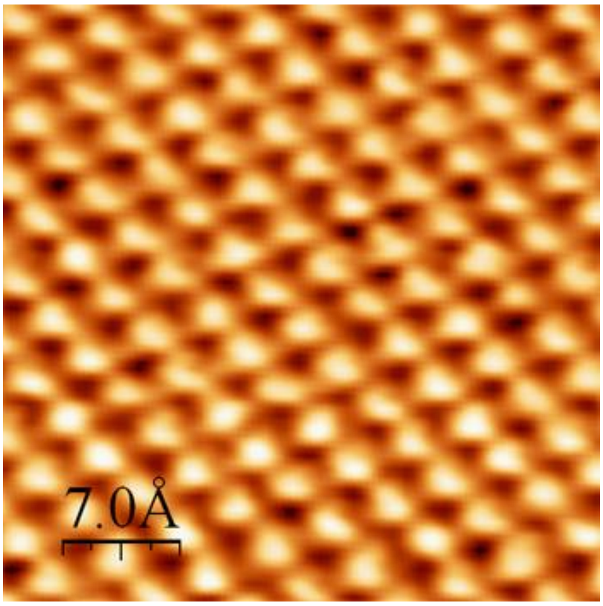
Double slit interference of waves

In this framework, a quantum object is a wave with some added properties that quantify the different values it can reach, giving the quantum wave a kind of granularity that the classical wave lack: it is not a wave, and is not a particle, but it has some properties that we attribute to waves or particles when one tries to think in the framework of classical physics.

Waves can produce characteristic patterns when interfering. Single electrons, going through an appropriate system, can produce a similar pattern. This shows that the “particle” description does not fit quantum objects[27].

[26] See http://www.hitachi.com/rd/research/em/doubleslit.html
[27] See for instance http://youtube.com/watch?v=ViQoUXu5uK0, http://youtube.com/watch?v=oxknfn97vFE and http://youtube.com/watch?v=oUolVZIuv18

Solid-state physics



Atomic lattice of pyrolytic graphite, observed with a scanning tunneling microscope[28]. The individual carbon atoms can be clearly resolved. They are ordered in a lattice, as is the vast majority of matter around us (except glass and glass-like materials).

An electron is not a classical particle. So, how can quantum mechanics help us to understand Ohm's law? In a metal, the electrons are wave-like, granted, but so what? It is important to realize that in matter the atoms are not randomly placed, on the contrary, they are ordered periodically along some patterns that depend on their interactions. Crystallography is the study of these patterns, which can be more or less complicated. The "wave-like" nature of the electrons matches with the periodicity of the atoms, and in a perfectly ordered metal an electron would encounter no resistance to its flow.

But there will always be disorder, such as that created by a small movement of an ion due to the thermal agitation. This will break the periodicity, and create a "brake" for the electrons. So if the electrical resistance decreases when the temperature decreases, it is because the thermal agitation of atoms also decreases, and they become more ordered. And since a perfect metal is impossible (there will always be some atoms missing, or any kind of defects), there is a minimum electrical resistance to metallic electrons, even at zero kelvin.

The application of quantum physics to the description of electronic properties of matter was a great success; all the mysteries that classical physics could not explain found explanations, from Ohm's law to positive Hall effect. It also explained the electronic properties of isolators and semiconductors, allowing the growth of the now flourishing electronic industry.

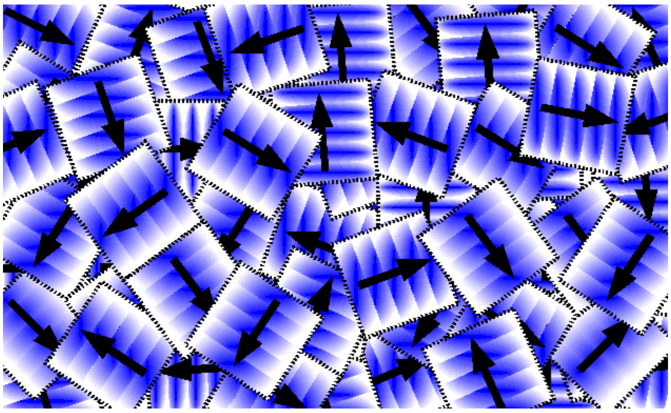
BCS theory

However, superconductivity cannot be understood in this framework alone. On the contrary, it predicts that a real zero resistance is impossible! The description had to be pushed a step further, and this was the great achievement of Bardeen, Cooper, and Schrieffer who finally succeeded in doing so in the late 50's. The theory they built that explains "regular" type I superconductivity is now named after them, the BCS theory.

[28] Photo credits: http://www.nanotec.es/applications/gallery/index.php?cat=miscelaneous

A key point of the description of the superconducting state is that it is a collective mode, which is something that quantum mechanics allows, under strict restrictions. A collective mode means that all the electrons of the superconductor are combined into a single quantum wave that extends over the whole sample. This contrasts with the metallic behavior, where a wave-electron has a very small size and all electrons behave independently.

In a superconductor there is only one wave of the size of the sample and with a single phase, encompassing the physics of all the superconducting electrons. The existence of this macroscopic wave can explain the properties of superconductors.



Conceptual illustration of free electrons in a metal.

In a metal, the free electrons all have an individual behaviour. They belong to a class of quantum particles that forbid collective behavior (their spin is a half integer, ±½: they are fermions).

Each electron has its own wave, and these waves can be deflected by any defaults, by the oscillations of the atoms (not represented here), or by other electrons. This scattering is responsible for the electrical resistivity, slowing down the electrons.

For example, since all the electrons are described by the same wave, to brake one electron all the electrons should be braked at the same time, which is something a single defect can not do. Thus superconducting electrons can flow without resistance, a direct consequence of their quantum state.

The question of quantum collective modes where a single quantum wave describes the properties of a very large number of particles, was first developed by Bose and Einstein (the Bose-Einstein condensation, now an active field of research). Liquid helium, when cooled below 2 kelvins, becomes a strange liquid ("superfluid"), with absolutely no friction, because the helium atoms become part of such a quantum collective mode. By analogy with superfluid helium (zero friction, zero resistance), Bardeen, Cooper and Schrieffer tried to describe superconductivity as a coalescence of electrons in such a collective mode.

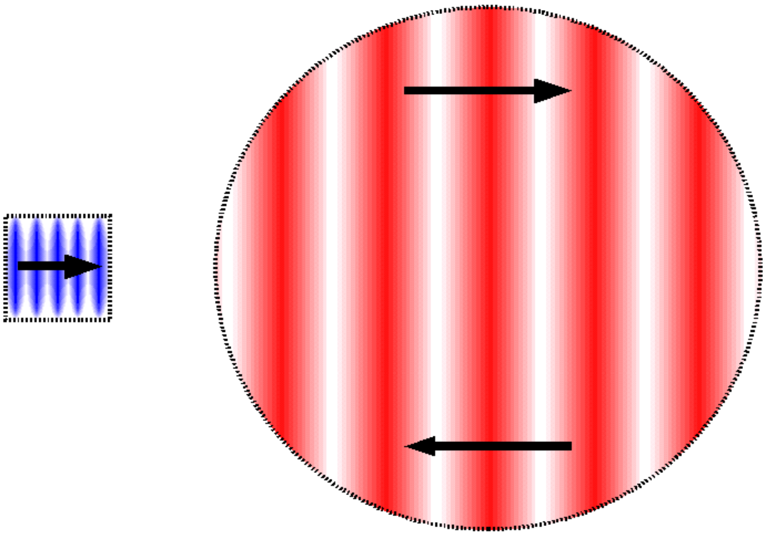
However, in theory this appears to be impossible: electrons belong to a class of quantum particles that are not supposed to. Their "spin", a quantum number that describes their magnetic properties, is ±½, a half integer that puts them in the category of "fermions". A consequence of this property is the famous "exclusion principle" of Pauli, stating that two electrons can not share the same quantum state.

Cooper pairs

The success of the BCS theory was to explain how, if the temperature is low enough, two electrons can behave has a pair (the Cooper pair).

The idea is that the ions of the metal provide a medium that will allow a small attraction to exist between two electrons and be responsible for the binding of the pair. At first it is not obvious, since both electrons have a charge of the same sign and will tend to repel one another. But in a metal, you have the same amount of ions (positively charged) and electrons (negatively charged), and on average it tends to balance out.

What Cooper showed is that a very tiny effect can occur below a certain (very low) temperature, with the help of the oscillations of the atoms in a material.



Conceptual illustration of a free electron (left) and a Cooper pair (right).

The particle nature of the electron is represented by the arrow: a free electron in a metal has a direction, and a velocity. The wave nature of the electron is represented by the colour variation between blue to white. Each electron is "spread" over a certain volume and must have a spin of either +½ or –½.

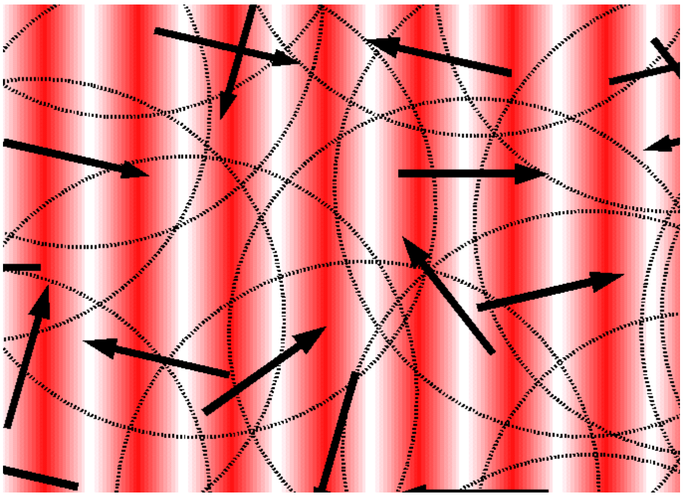
A Cooper pair consists of two electrons travelling in opposite directions (two arrows). This object is spread over a larger distance. The quantum wave is shown as a change from red colour to white and back.

Cooper pairs of electrons keep breaking and reforming all the time. Electrons in a Cooper pair have opposite spin (+½ and –½), so the total spin is 0.

The effect is something like "an electron attracts an ion that attracts an(other) electron". Forgetting the middle man, we get "an electron attracts an electron", and these two electrons have opposite velocity. They form a "Cooper pair".

Being a dynamic process, Cooper pairs keep forming, breaking and reforming all the time. Of course, this is also a weak interaction, and the electrons are not bundled in a tight volume. On the contrary, a Cooper pair can be quite large: the typical size is called the coherence length, ξ, and can vary from a few Ångstroms to thousands.

The important point from quantum dynamics is that this quantum object is no longer a single electron or a "fermion". The two electrons have opposite spin (+½ and –½), so the Cooper pair has zero total spin, an integer that makes it a "boson". Bosons are a class of particles that are allowed to form a collective mode by the laws of quantum mechanics.



Conceptual illustration of Cooper pairs in a superconductor.

In conclusion, superconductivity exists because electrons can form pairs below T_c , pairs whose quantum nature allows to coalesce in a collective coherent mode, where all the quantum particles will have the same phase and build up a single macroscopic quantum wave extending across the entire material.

The size of Cooper pairs is quite large (ξ of order of 100 nm, much larger than the distance of two atoms (of order of 0.1 nm). In a superconductor, they overlap a lot.

Cooper pairs are bosons (their spin is an integer, 0), and can belong to a collective mode. This means that although they overlap, they will define a single quantum wave, spread over the whole superconductor sample. This phase coherence is responsible for all the superconducting properties.

Superconductivity is quantum physics that you can practically touch!

Properties of superconductors

There are two complementary descriptions of the superconducting state. The thermodynamic approach is based on a very general argument, and describes the superconducting transition as a true phase transition, between two different electronic states. The microscopic approach, based on quantum physics, addresses the very nature of these two electron systems and explains the existence of Cooper pairs and their condensation into a quantum collective mode. These two approaches describe complementary aspects of the superconducting state, and together they constitute efficient tools to understand the properties of a superconductor.

Electrical properties: Zero resistance

The electrical properties of superconductors are the most dramatic: the electrical resistivity vanishes just below T_c. This zero resistance is a direct consequence of the collective nature of the Cooper pair system: since a single quantum wave describes their physics, it is not possible to slow down only one electron or one pair. All the Cooper pairs have to be affected at the same time. A defect in the ion lattice can deflect a single metallic electron, but can not directly interact with the whole electronic system.

With nothing to slow down the electrons, the superconducting current can flow without resistance. However, superconductivity appears quite fragile, and can only exist within limiting values for some factors. Temperature is the first of them, obviously: above T_c no superconductivity exists.

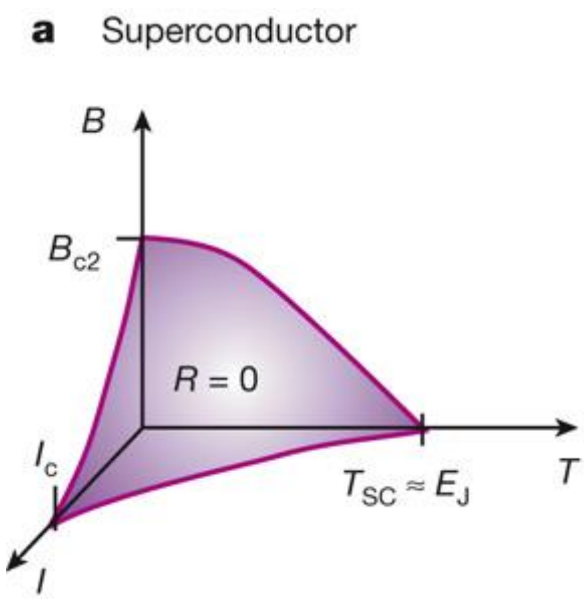
A magnetic field above a certain value B_c will also destroy superconductivity. This was discovered early by Kammerlingh Onnes, who tried to produce a large magnetic field using a superconducting coil. Thus, the value of magnetic field is a limiting parameter for the existence of superconductivity. In fact, the interaction of the magnetic field and superconductivity is complicated, and we will explain this in more detail later.

The current is a third limiting factor. A superconductor has a limiting current I_c that it can carry (or rather a limiting current density J_c, in A m^{-2}, to take into account the fact that a superconductor with a larger cross-section can carry a larger current). With a current larger than this threshold value, superconductivity vanishes and the usual metallic properties are restored.

Hence, superconductivity only exists at low temperature, low magnetic field and low current. Above any of these parameters and the electrons behaves as normal metallic electrons.

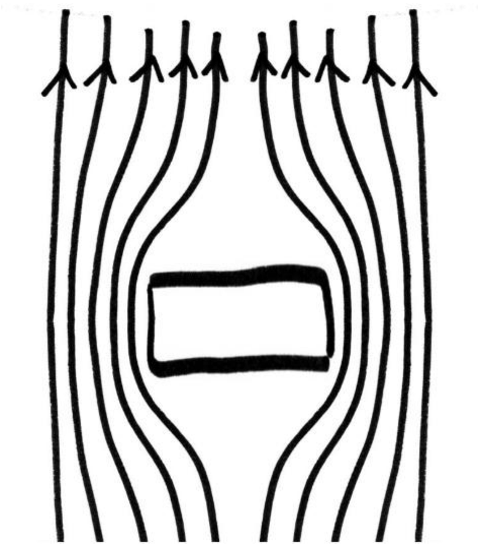
This is what is called a "phase diagram", the combination of parameters that decide whether the superconducting configuration or the metallic configuration is the favored one for the electronic system (thermodynamic approach).

Each superconducting material will have different values of I_c, B_c and T_c. In order to design devices using superconductors, care has to be taken to remain within these boundaries.



Superconductivity can only exist when the temperature, the magnetic field and the current are not too high. The threshold for each parameter depends on the value of the others.

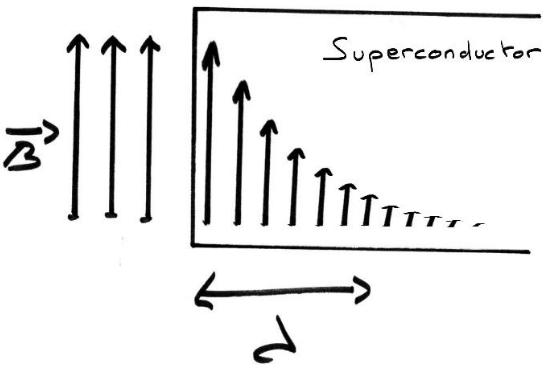
Magnetic properties: Meissner effect



We have not yet addressed the question of why a strong magnetic field can destroy superconductivity. The reason is not obvious. The magnetic field affects the phase of the superconducting wave, so superconductivity and magnetic fields are not compatible.

In fact, a superconductor will repel any magnetic field from its volume. The thermodynamic approach tells us that expelling the magnetic field represents an energy cost to the system. If the cost is higher than the energy that the system gains by becoming superconducting, then it will stay metallic. This explains why a high magnetic field kills the superconductivity state.

A superconductor can expel a magnetic field inside its volume by superconducting currents at the surface that produce a magnetic field exactly opposite of the applied magnetic field. Thus a superconductor behaves as a perfect diamagnetic material: this is the Meissner effect.



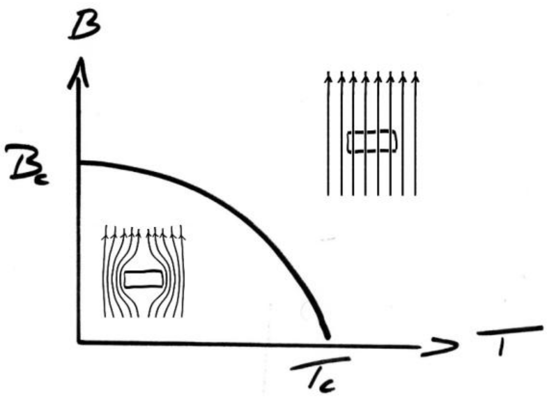
The magnetic field only enters the superconductor on the thickness necessary for these “screening supercurrents” to exist. The characteristic dimension of this thickness is called the “penetration length”, λ, and is around 100 nm. Superconductivity can only coexist with a magnetic field on this scale length.

A superconductor with a size smaller than λ will not be a perfect diamagnet, because the surface screening currents will not have enough space to efficiently cancel the applied field. This property, the expulsion of magnetic flux from the bulk of a superconductor, is not related to the absence of resistivity in a superconductor. On the contrary, if one considers a hypothetic perfect metal (metallic electrons with zero resistivity) the magnetic behavior would be different. Lenz’ law does not forbid magnetic flux, only changes in magnetic flux.

The Meissner effect demonstrates that a superconductor is more than just a perfect metallic conductor; it is also a perfect diamagnet. This property is therefore often considered the most important of a superconductor.

Magnetic properties: Flux vortices

The total flux expulsion above describes so-called "type I" superconductors. The phase diagram is easy to describe; either the electrons are superconducting and the flux is expelled, or they are normal metallic electrons. The higher the magnetic field, the lower the temperature superconductivity can exist, till it no longer can.

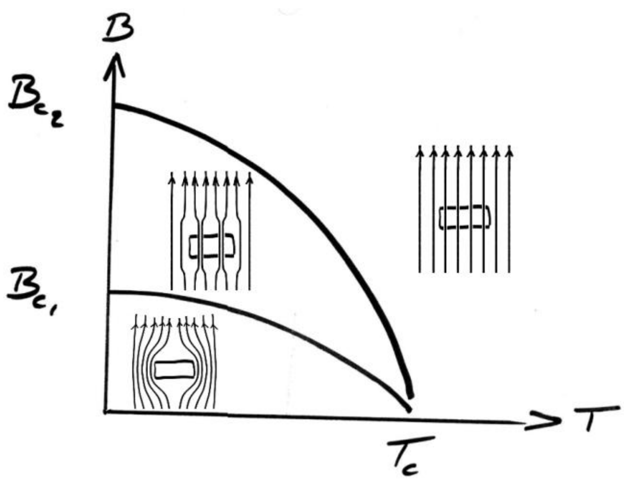


Phase diagram for a type I superconductor

The critical fields of type I superconductors are rather low (hundreds or thousands of gauss). They are a measure of the strength of a Cooper pair bond, and this is a rather small energy (the electron-ion-electron is a weak interaction).

A second family of "type II" superconductors presents a more complicated phase diagram. Below T_c and at a weak magnetic field, they demonstrate the Meissner effect just like type I. But above a first critical magnetic field B_{c1} they lose their perfect diamagnetic properties. They remain superconducting with a zero resistivity, but their diamagnetism diminishes quite rapidly up to a second critical field B_{c2} where superconductivity disappears totally.

This intermediate region between B_{c1} and B_{c2} is called the "Abrikosov phase" or "mixed state". Here, the superconductor is still a diamagnet, but no longer a perfect one; part of the magnetic flux goes through the sample.

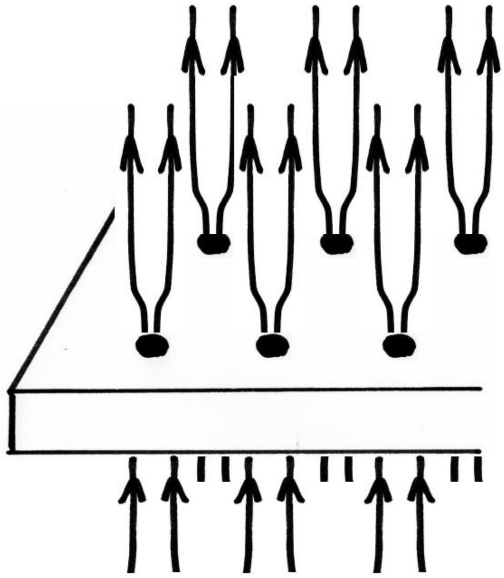


Phase diagram for a type II superconductor

As mentioned earlier, the magnetic flux cannot coexist within a pure superconducting system, except on the scale of the penetration depth. The penetration of the magnetic flux is only possible because a small part of the sample, shaped like a tube, loses its superconducting properties and becomes metallic. These tubes are called "vortices" and they act as channels for the magnetic field.

More precisely, the superconducting wave must vanish within the core of the vortex, where the electrons are normal metallic electrons. The core diameter is given by the coherence length ξ, which represents the smallest length that is needed for the superconducting wave to vanish, since it corresponds to the characteristic size of a Cooper pair. But Maxwell's laws forbid flux lines to exist on their own. Therefore a supercurrent flows around around the core (hence the name “vortex”) and define the flux of the vortex. So the magnetic field around the vortex cores decreases exponentially around the typical size of the penetration depth λ.

A thermodynamic argument explains the existence of vortices. The type II superconductors do a trade off of energy to define their preferred configuration. Totally repelling the magnetic field represents a cost for the system. In a type II superconductor, a vortex appears when the applied field is above B_{c1}. Since a vortex core is no longer superconducting, it represents an energetic loss for the system. But then the magnetic field can go through the sample reducing the magnetic pressure: the superconductor is no longer a perfect diamagnet, and this represents a gain for the sample. If the diameter core ξ (the loss) is smaller than the magnetic field penetration depth λ (the gain), the balance is favorable and creating a vortex is thermodynamically favorable. The higher the applied field is, the more numerous the vortices are. When the magnetic field becomes too high (above B_{c2}) the vortice cores get in contact with each other and superconductivity disappears across the sample.


“Metallic” vortices channel the magnetic flux through a superconductor

In a type I superconductor the coherence length is larger than the penetration depth, so the creation of a vortex is never a favorable trade off. Thus the thermodynamic approach can explain the phase diagram of all superconductors.

A very peculiar feature of the vortices is that they all carry the same flux, φ_0, which corresponds to the smallest quantum of flux that can be defined by a supercurrent, the flux of two electrons. This is a consequence of the quantum collective mode that describes the Cooper pairs. Since there a single wave, there is a single phase that must be continuous around the vortex discontinuity.

A vortex is a strange object: it represents a quantum of flux, but is also a macroscopic object, since the thickness of the sample represents its length. Moreover, the vortices arrange themselves in an ordered fashion (hexagonal lattice): the existence of order in such a fuzzy system originates from the repulsive interaction between two flux lines. Their small size prevents them from being easily observed, but research labs have developed various techniques to image them[29].

[29] See http://www.fys.uio.no/super

The existence of vortices was first postulated from thermodynamic considerations (similar to the above paragraph) by Abrikosov in the mid 50's, but his supervisor, physics Nobel prize laureate Lev Landau, thought it was unlikely and prevented him from publishing his speculations. However, shortly thereafter experimental results began demonstrating the existence of quantified flux lines in the mixed state of superconductors. Abrikosov was co-laureate of the 2003 Nobel prize in physics for his work on superconductors.

The trade off that is represented by the vortices allows superconductivity to exist with a much higher magnetic field. B_{c2} can reach several tens of teslas, even hundreds in the case of cuprate superconductors.

As magnetic flux goes though the vortices, the superconductor in this mixed state ("Abrikosov phase") is no longer a perfect diamagnet. It does remain partly diamagnetic, since the supercurrents around the vortex screen the magnetic field, but as the number of vortices increases, the diamagnetic properties vanish rapidly. In spite of this, superconductivity still exists around the vortex cores and the electrical resistivity is still zero.

Magnetic properties: Pinning

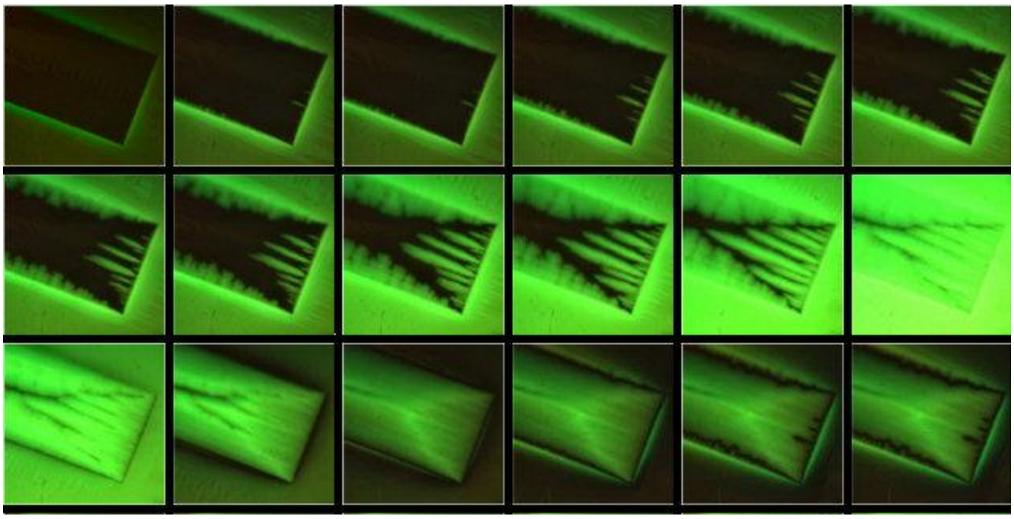
The number of vortices within a superconductor is in theory determined by thermodynamics. For a given applied magnetic field, there is a given number of vortices that will optimize the "status energy" of the system. This number represents the best trade off for the superconductor. When the applied magnetic field is increased, the number of vortices should increase. This means that new vortices should enter the superconductor, and that the vortex density will increase inside. Obviously, when the magnetic field is decreased, the number of vortices should also decrease and some of them should go out of the sample for the system to reach its preferred configuration.

An important point of this line of reasoning is that each vortex is free to move. In a superconductor with absolutely no defects, there is nothing in theory that should prevent a vortex from moving. Whatever the physical place of the vortex within the material, the energy trade off would be the same.

However, this is not the case. A vortex is easily pinned and can be difficult to move. In any material, there are always some defects – places in the sample where an ion is missing, or is stuck in a wrong place. Superconductivity is a bit weaker here than in other places. If superconductivity is destroyed around this defect, the system would not lose as much energy as if it happened somewhere else, since superconductivity is weak in that place anyway. Having a vortex core going through this defect will represent a better trade off than having a vortex core elsewhere. Thus, the vortex is pinned and will move only if a force is exerted on it that can overcome the energy gain represented by the vortex staying at the defect. And since all the vortices interact with themselves, pinning a few of them can be enough to pin a large quantity.

A consequence of this is that when the applied magnetic field is increased, not all the vortices that should be inside can enter the superconductor; on the other hand, when the magnetic field is decreased not all the vortices that should have been expelled can get out. This creates a magnetic hysteresis, and complicates the description of vortices a lot. Because hysteresis is a non-equilibrium phenomenon, the system is in a state that depends on its previous history rather than its preferred configuration.

The system cannot reach its preferred configuration because in order to do so it has to provide the energy that is needed to move the pinned vortex. If this energy is too large then the system is stuck in a "metastable" state. A metastable system is in a locally preferred state, the most energy-favourable state within reach of the system. The globally preferred state, the "real" stable configuration, is out of reach.



Magneto-optic studies of a slab of niobium[30]. The intensity of the magnetic field is shown in green. In the two upper rows of photos, an external field is applied and its value is increased. First, the niobium slab remains black (Meissner state), then the magnetic field penetrates the sample. The scale is too large to distinguish individual vortices, so the lines are macroscopic features.

Photos in the bottom row show the behavior of the sample when the external field is reduced to zero. Some magnetic flux remains trapped within the niobium slab, whereas the most favorable thermodynamic trade off would be to expel all vortices. The system is thereby stuck in a metastable state. This experiment is similar to the MOSEM High-Tech Kit experiments 4.3.3 and 4.3.4.

There is some pinning in every superconductor. In some, the pinning is small, and the number of vortices is almost the preferred number. In these samples, the magnetic hysteresis (when the applied field is increased and then put back again to zero) is very small. A vortex can be moved easily. That means that the "equilibrium description" is adequate.

[30] Credits: Ames laboratory, http://cmp.ameslab.gov/supermaglab/Data/MO

But another consequence is that the critical current density of such samples is very low. Indeed, a current flowing through the sample will create a force on magnetic flux; the current will tend to make the vortex move. But the movement of a vortex, at the difference of the supercurrent, will dissipate some energy. This slows down the supercurrent. Thus, Cooper pairs carry the current, but an electrical resistance will appear!

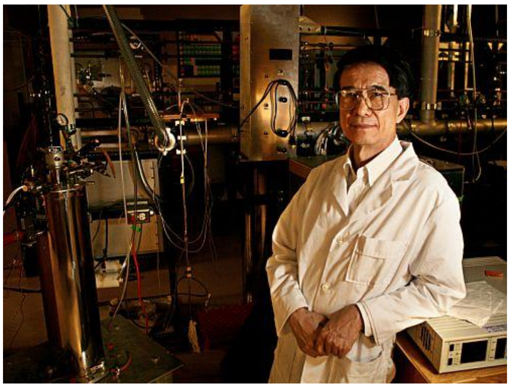
On the other hand, some superconductors have strong pinning. These samples can pin a magnetic field efficiently with the vortices that are not allowed to move. These samples will have a larger critical current density. This vortex freezing is the key to explain the magnetic levitation of superconductors properly (see the MOSEM High-Tech Kit experiments 4.3.2, 4.3.3 and 4.3.4).

Do we understand superconductivity?

The understanding of superconductivity, the BCS model and the thermodynamic approach, was one of the greatest achievements of solid state physics. By the late 60's it seemed that superconductivity was completely understood, and that only details remained to be fixed. All properties were taken into account by these theories, and it was expected that no material could become superconductors at temperatures above around 30 K because the Cooper pairs were so fragile. Some strange superconductors were found that did not totally fit within this framework, dubbed "unconventional superconductors". Their understanding was of interest from a fundamental point of view, but little industrial outcome were expected from them since their critical temperature were low (below 20 K at best, and often below 1 K).

But everything changed in 1986, when two IBM researchers in Zürich published an article were they demonstrated the existence of superconductivity at temperature as high as 35 K ("high temperature" is a relative business in cryogenic physics). More to the point, the compound they studied was part of a large family of samples, the cuprate perovskite, and rapidly other members of this family showed T_c as high as 135 K!

K. Alexander Bednorz and J. Georg Müller from IBM Zürich discovered the first cuprate superconductor[31].



Paul Chu discovered the first superconductor with critical temperature above the boiling point of nitrogen[32], allowing liquid nitrogen for cooling.

[31] Photo credit: http://www.manep.ch
[32] Photo credit: http://blogs.chron.com/sciguy/archives/2007/03/listen_an_inter_1.html

These discoveries opened up the possibility devices cooled with nitrogen instead of helium. The boiling temperature of liquid nitrogen, which is quite cheap and easy to handle, is 77 K. The ultimate hope for a room temperature superconductor was also invigorated. The understanding of these materials became one of the hottest subjects in physics. And with these materials, demonstration of superconductivity using liquid nitrogen was now possible.

More than twenty years after the discovery, these materials remain a puzzle to the community. Cuprates, also called copper oxides, are layered compounds with very anisotropic properties. All the members of this family have in common planes made of copper and oxygen (CuO_2), and it is now clear that the superconductivity originates from these planes.

It is clear that Cooper pairs exist, but some of their properties are different, notably their symmetry. But most importantly the origin of the Cooper pairs is strongly debated, and it seems that the ions of the sample are not responsible for their formation. This crucial question is not yet resolved and is still today the topic of numerous studies and hot discussions within the community of researchers.

One of the complications that render the problem so difficult is that the electrons are confined within the CuO_2 planes – they are not as free as in conventional metals. This confinement greatly increases the importance of interactions between electrons, and so far these have been difficult to represent properly. Now there is a branch of solid state physics research that is dedicated to understand how these strong interactions can evolve.

They work not only with the cuprate family but all kinds of new families that are synthesized with structures that increase these electronic interactions. In these families, strange electronic behaviors are observed (superconductivity yes, but also spin liquids, colossal magneto resistance, strong thermoelectronic properties). This is a very exiting field where experimental work, material science and theoretical work is entangled. Research is ongoing, as a lot remains to be uncovered.

Applications of superconductivity

Superconductivity with its extraordinary properties can be used, and is used, in many various devices. The ever present need for cooling renders huge scale applications a bit complicated. “High temperature superconductors” can work in liquid nitrogen, which make them much easier to handle, but they unfortunately offer several drawbacks.

Firstly, they have large critical temperatures (T_c) and large critical magnetic fields (B_c) even at 77 K, but generally they offer low critical current densities (J_c), even if some progress have been made lately. And secondly, their quality is extremely sensitive to the quality of their crystallographic structure: the presence of defects or misalignments of the CuO_2 planes can easily reduce J_c by additional orders of magnitude. So both conventional and non-conventional superconductors are put to use for different purposes.

The most obvious application for a metal without electrical resistance is to carry electrical current from a power plant to the user. Indeed, part of the electrical energy converted at the plant is lost by joule effect in the wire.

The technology of copper wires that have to carry such a high density of energy is an art in itself, since the heat coming from the flow of current may damage them. Using superconductor wires would save some energy, and smaller diameter wires would free up space (e.g. for more wires if necessary).

For such applications where the superconductor is spread across a large distance, the use of liquid nitrogen is a necessity if the price of this technology is to be interesting, which again implies using high temperature superconductors.

The Nexans company develops superconducting cables with promising capacities[33].

The generally low J_c, and the difficulty of making wires from the cuprates are huge technological challenges, but some prototypes are beginning to appear. This technology is interesting for big cities that need to transport large amounts of electrical energy over short distances. A first line is going to open in Long Island using this technology.

Another application for a zero resistance metal is setting up a high magnetic field. The circulation of a current in a coil produces a magnetic field, but to obtain a large field a huge amount of electrical energy is needed. Some specialized centers in Europe, Japan or USA uses copper coils to reach up to 30 T, but these magnets dissipate 20 MW when at full field! To evacuate such a power, an enormous flow of water is needed, and the electricity bill is quite expensive…

Kamerlingh Onnes figured out early that a superconducting coil would be ideal for producing magnetic fields. Not only will zero resistance lower the energy needs, but once the current is flowing the coil can be closed on itself, as the current will keep on flowing even if the current source is taken away. Onnes tried to build such a magnet but was heavily disappointed, because he realized that the magnetic field produced by the coil could destroy superconductivity: he used materials with low critical fields… Using type II superconductors with high critical fields, it is now possible to reach 24 T in an all superconducting coil[34].

[33] See http://www.nexans.fr
[34] See http://www.nims.go.jp/eng/news/press/2011/09/p201109070.html

Generally, these coils are made using conventional superconductors, because the technology of making wires is simpler, but that means using liquid helium. Superconducting coils need infinitely less power compared to resistive electromagnets and can fit in the corner of a room instead of needing a whole building: they are used whenever high magnetic fields are needed.

When are high magnetic fields needed? In research laboratories, magnetic fields are used as a tool to probe the properties of matter. In these labs, superconducting coils are common, and several companies compete for the best performances. A few laboratories specialize in very high magnetic fields[35].

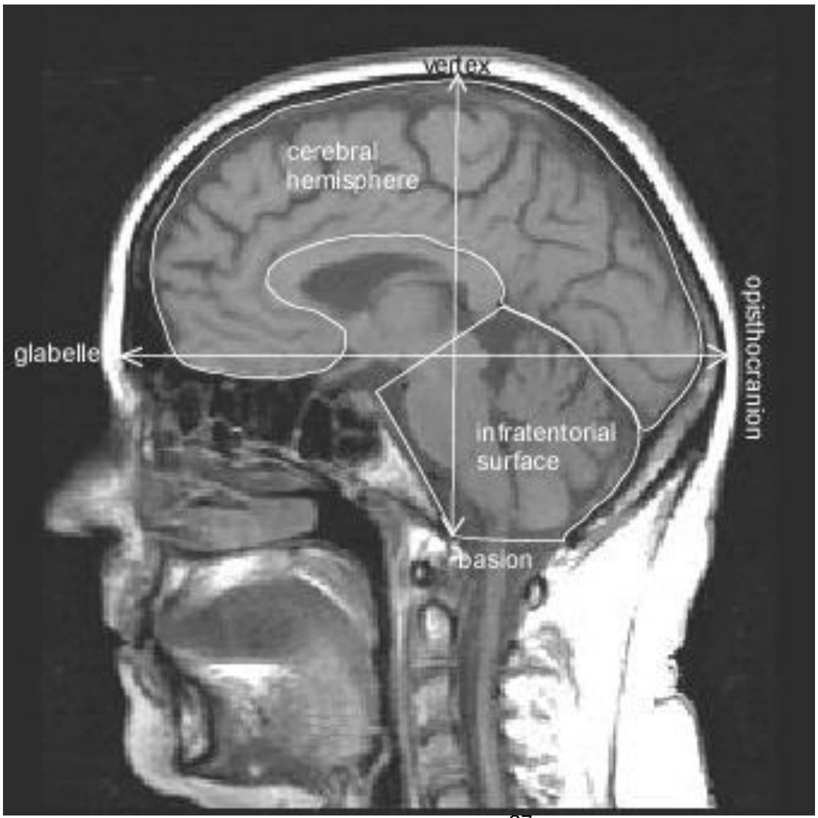
In the most recent coils, a helium-free option is proposed: these coils are still made with conventional superconductors, but the cooling power comes from an engine (a *very* efficient fridge).

Superconducting magnet section number 1000 for LHC was installed on 5 September 2006 in the 27 km long underground tunnel close to Geneva.

Recently, the CERN laboratory of high energy physics opened the Large Hadron Collider (LHC), its new tool to probe the very fabric of matter[36]. LHC is a 27 km long circular particle accelerator. The largest and most complex machine in the world, it is filled with superconducting magnets that are used to bend the trajectory of the particles as they pass by at close to the speed of light. The quantity of helium needed to cool the whole system is staggering.

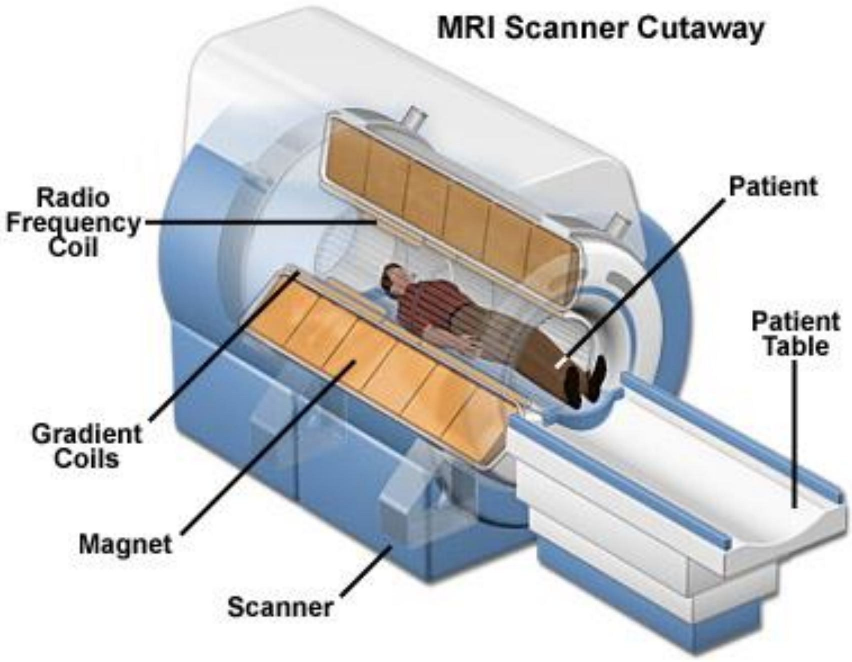
[35] See for example http://www.magnet.fsu.edu
[36] Photo credits and more information, see http://public.web.cern.ch/public

High magnetic fields are also needed for Magnetic Resonance Imaging (MRI), a technology used to image the interior of a body that has become a great diagnostic tool in hospital. To operate, the body of the patient needs to be immerged in a magnetic field, and a high value allows a greater resolution[38].



MRI cross-section of a human head[37]

The tunnel inside which the patient rests is in fact a superconducting coil, in a bath of liquid helium. MRI magnets are now the largest market for superconductors.



Structure of a Magnetic Resonance Imaging machine[39]

[37] Photo credits: http://www.evolhum.cnrs.fr/guihard/index.html
[38] See http://www.e-mri.org for a presentation of this technology
[39] Photo credits: http://www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/

High magnetic fields are also needed for magnetic levitation trains (maglevs). The first commercial maglev train line in Shanghai[40] uses regular electromagnets.[41]

Japan has built a demonstration track[42] where they set the current speed record of 581 km/h. [43]

Now Japan Rail is planning a superconducting maglev track between Tokyo and Osaka via Nagoya to superseed the Shinkansen[44] bullet train.

This track[45] will not be ready before 2025, probably closer to 2050.

It is still not clear whether levitating trains will be the future, but Japan Rail thinks it can be useful at least some places[46].

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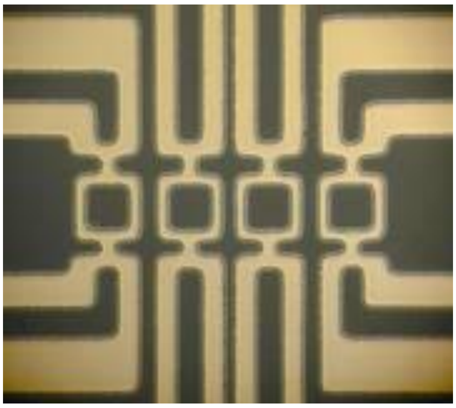
40 See http://en.wikipedia.org/wiki/Shanghai_Maglev_Train
41 Photo credits: http://www.chinatourstravel.com/china-culture-and-traditions/shanghai-maglev-train-ride.html
42 See http://en.wikipedia.org/wiki/JR-Maglev
43 Photo credits: http://flutuante.wordpress.com/2010/01/16/levitation/
44 See http://www.maglev.net/news/go-ahead-for-japanese-maglev/
45 Photo credits: http://www.japanprobe.com/2010/10/22/tokyo-to-osaka-maglev/
46 See http://www.huffingtonpost.com/yoshiyuki-kasai/superconducting-maglev-a-_b_971425.html

Superconductors are also used in more surprising applications. Their properties allow them to build very good electronic filters for example.

A filter is a device that is able to differentiate a signal at a given frequency from others, and among its many applications it is heavily used in telecommunication technology, where all cell phone discussions have to be fitted in a given frequency range.



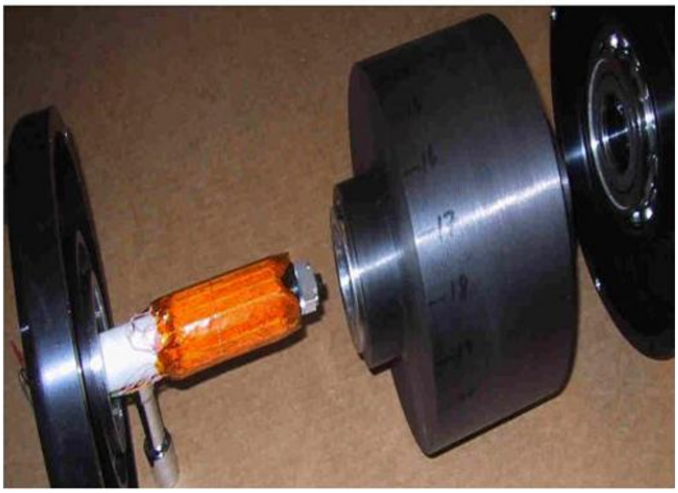
A microphotograph of a superconducting device which measures about a thousandth of a millimeter in size[47].

Another promising application is energy storage, either through flywheels or using magnetic coils. Indeed, a major problem for electricity suppliers is that electric energy is very difficult to store.

Batteries are not very efficient and their capacities are limited, so power plants have to adjust production according to the need in real time, which is difficult in the case of nuclear plants and most renewable energy sources, with the exception of hydroelectric plants. In order to reduce dependence on coal and oil it is necessary to find new ways to store energy that is easily accessible as electricity.

A flywheel is a heavy disk that is set spinning: it stores energy as kinetic energy. Traditional flywheels lose energy through friction.

A levitating flywheel[48] on the other hand would lose much less energy and can become a technological solution for power plants.



And of course, a superconducting coil can store energy as an electric current without any dissipation at all, ready to be released at will through the associated magnetic field.

The magnetic properties of superconductors allow the fabrication of the devices extremely sensitive to magnetic field. This is made possible by the Josephson effect, which is obtained when two superconducting quantum waves are made to interfere (similar to the interference of classical waves, such as in the Young double slit setup for the light).

47 Photo credits: http://www.superconductivity.bham.ac.uk
48 Photo credits: http://www.magnemotion.com

Using these devices it is possible to build an apparatus that can measure vanishing small magnetic fields.

These are very useful in research labs, but they are also beginning to be of interest for other domains such as medicine or geology.

During the past years a prototype of a LTS SQUID gradiometer system for mobile applications measuring the full tensor of the Earth’s magnetic field gradient with extremely high sensitivity was built at IPHT Jena[49].

Conclusion

Understanding superconductivity had been considered as the Holy Grail for many physicists before quantum mechanics succeeded in explaining it.

After the BCS theory, superconductivity seemed to be tamed, but in the last 25 years the cuprate family has demonstrated that it was not the end of the journey. Understanding high-temperature superconductivity in detail is still a work in progress, and the challenge of the cuprate family still stands.

Additionally, in 2007 a new family of superconductors was found that excited the researchers. Without any copper or oxygen, this pnictide family, with layers of iron and arsenic, reached critical temperature of 56 K. The studies are on going to understand whether the origin of superconductivity in this family is the same as for the cuprates, or if other mechanisms are involved. Science is going on.

[49] See http://www.ipht-jena.de

Questions & Answers about superconductivity

What is the temperature of liquid nitrogen?
The boiling temperature when liquid nitrogen turns into gas is 77 K or -196 ^{o}C.

Why can liquid nitrogen boil and still be cold?
A liquid cannot be at a temperature above its boiling temperature. A bucket of water put inside a 300^{o}C oven will warm up till 100^{o}C. Then the the water will boil, and the water temperature stays at 100^{o}C until it has all boiled away. The water will appear cold to someone used to the hot temperature of the oven. Liquid nitrogen boils at -196 ^{o}C, so it seems cold to us even when it is boiling.

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 handled 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 do 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 drops can be observed, due to a mechanical oscillation of the drop.

Is there really liquid helium in a 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 many alloys, so it is not really a rare property. However, superconductivity only appears at extremely low temperatures.

Do the cuprate superconductors exist in nature?
No, they are made in laboratories. Similar crystallographic structures do exist naturally, though.

Are cuprate superconductors dangerous?
Mechanically no; they are quite fragile and break easily. However, like certain metal superconductors like mercury, some of the elements making up the cuprate superconductors are poisonous. It is advised to wash your hands after touching superconductors, and/or use gloves when you work with them.

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 slow down 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 there is little to brake the rotation. One can feel some bumps in the rotation, though.

How does a maglev work?
There are various maglevs 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 is used?
The magnets that are used here are Neodymium-Iron-Boron alloy. They are the strongest magnets available today; we call them “supermagnets”.

Are supermagnets dangerous?
Due to their strength, supermagnets are attracted to each other with great force and speed, and they can damage your fingers or other body parts that get caught in the middle. If nothing comes between the magnets they often get crushed into sharp pieces, and any dust that comes off is poisonous. So treat them carefully.

Bibliography

References

Introduction

Angell, C., Henriksen, E. K., & Kind, P. M. (2007). *FYS21 - et prosjekt om modellering og vitenskapelig arbeids- og tenkemåte i fysikkundervisningen*. NorDiNa,, 3(1), 86-92.

Angell, C., Kind, P. M., Henriksen, E. K., & Guttersurd, Ø. (2008). *Implementation of empirical-mathematical modelling in upper secondary physics: teacher interpretations and considerations. 9th Nordic Research Symposium on Science Education*, Reykjavik, Iceland

Danielsen, T.A. (2008). *Dataloging i fysikkundervisningen i videregående skole*. Master thesis, University of Oslo

Gilbert, J. K. (2004). *Models and modelling: routes to more authentic science education.* International Journal of Science and Mathematics Education, 2, 115-130.

GIREP (2006). *Modelling in physics and physics education.* http://www.girep2006.nl

Greca, I. M., & Moreira, M. A. (2002*). Mental, physical and mathematical models in the teaching and learning of physics.* Science Education, 86, 106-121.

Guttersrud, Ø. (2008). *Mathematical Modelling in Upper Secondary Physics Education. Defining, Assessing and Improving Physics Students' Mathematical Modelling Competency*. Unpublished Ph.D thesis, University of Oslo

Henze, I., van Driel, J., & Verloop, N. (2007). *The change of science teachers' personal knowledge about teaching models and modelling in the context of science education reform.* International Journal of Science Education, 29(15), 1819-1846.

Hestenes, D. (1987). Toward *a modeling theory of physics instruction.* American Journal of Physics, 55(5), 440-454.

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

Minds-On Learning and Teaching

Bar, V., Zinn, B. , Goldmuntz, R. (1994). "Children's concepts about weight and free fall." *Science Education* 78(2): 149-169.

Bogdanov, S. R., Viiri, J. (1999). Students' understanding of the force concept in Russia and Finland. *Research in Science Education - Past, Present, and Future Vol.1*. in Komorek, M., Behrendt, H. , Dahncke, H. , Duit, R. , Graeber, W. , Kross, A. (eds) Proceedings Second International Conference of the European Science Education Research Association, Kiel, September 1999**:** 113-115.

Brown, D. E. (1994). Facilitating conceptual change using analogies and explanatory models. *International Journal of Science Education* 16(2): 201-214.

Driver, R. and Easley, J. (1978) Pupils and paradigms: a review of literature related to concept development in adolescent science students. *Studies in Science Education*, 5, 61 – 84.

Driver, R. and Erickson, G. (1983) Theories in action: some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education*, 10, 37 – 60.

Duit, R. (1987) Research in students' alternative frameworks in science topics, theoretical frameworks, consequences for science teaching. In Novak, J.D. (ed) *Proceedings of the Second International Seminar, Misconceptions and Educational Strategies in Science and Mathematics,* vol. 1 (pp. 151 – 162) Cornell University, 26 – 29 July 1987.

Hancock, C. H. (1940). An evaluation of certain popular science misconceptions. *Science Education* 24(4): 208-213.

Kaiser, M. K., Jonides, J. , Alexander, J. (1986). Intuitive reasoning about abstract and familiar physics problems. *Memory and Cognition* 14(4): 308-312

McDermott, L. (1984) Research on conceptual understanding in mechanics. Physics Today, 37, 24 – 32.

Elaine Reynoso, H., Enrique Fierro, H. , Gerrdo Torres, O. , Perez de Celis, J. (1993). The alternative frameworks presented by Mexican students and teachers concerning the free fall of bodies. *International Journal of Science Education* 15(2): 127-138.

Schmidt, H. (1997) Students' misconceptions – looking for a pattern. *Science Education,* 81(2) : 123 – 136.

Schoon, K.J. and Boone, W.J. (1998) Self-efficacy and alternative conceptions of science of preservice elementary teachers. *Science Education*, 82(5) 553 – 568.

Taber, K. (1996). Chlorine is an oxide, heat causes molecules to melt, and sodium reacts badly in chlorine: A survey of the background knowledge of one A-level chemistry class. *School Science Review,* 78(282): 39-48.

Van Hise, Y. A. v. (1988). Student misconceptions in mechanics: An international problem ? *The Physics Teacher* 26(11): 498-502.

Willson, M., Williams, D. (1996). Trainee teachers' misunderstandings in chemistry: Diagnosis and evaluation using concept mapping. *School Science Review* 77(280): 107-113.

Experimental activities

Einstein, A. [Review of Hermann von Helmholtz. Zwei Vortrage uber Goethe. W. Konig, ed. (Braunschweig: Vieweg, 1917).] Die Naturwissenschaften 5 (1917): 675. As quoted in: David Cahan's 666-page book Hermann von Helmholtz and the Foundations of Nineteenth-Century Science (pg. v).

Fredrickson J.E., Moreland L., *Electromagnetic Induction: a computer-assisted experiment*, AJP Volume 40, September 1972, 1202-1205

Ireson, G. & Twidle, J., *Magnetic braking revisited: activities for the undergraduate laboratory,* Eur. J. Phys. **29** (2008) 745–751

Kingman. R, Rowland S.C. & Popescu S., *An experimental observation of Faraday's law of induction*, Am. J. Phys. 70 (6), June 2002, 595-598

Leff, H.S. (1990) *Illuminating Physics with Light Bulbs*, The Physics Teacher 28 (30)

Manzanares J., *An experiment on magnetic induction pulses*, Am. J. Phys. 62 (8), August 1994, 702-706

Santi, L. & Michelini, M. (2006) *An interpretative model to evaluate the thermal conductivity of the filament in a bulb lamp*, Proceedings GIREP 2006 (Modelling in Physics and Physics Education).

Shackelford, B.E. (1916) *Temperature and Blackening Effects in Helical Tungsten Filaments*, Phys. Rev. 8 (470)

Wagner, W.S. (1991) *Temperature and Color of Incandescent lamps*, The Physics Teacher (176)

Young & Freedman, *University Physics*, 12th edition, Addison Wesley 2008

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.

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 centered 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 high temperature superconductors.

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.

Textbooks on superconductivity (university level)

Superconductivity: Fundamentals and Applications, by Werner Buckel and Reinhold Kleiner, Wiley-VCH; 2 edition
Modern presentation of superconductivity with links to recent research results and a discussion of applications.

Superconductivity: Physics and Applications, by Kristian Fossheim and Asle Sudbø, Wiley
Modern presentation of superconductivity with links to recent research results and a discussion of applications.

Introduction to Superconductivity, by Michael Tinkham, Dover Publications Inc.
The classical reference 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

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 T_c 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 go too deep into the quantum explanation and prefers to insist on the understanding, but with the help of many equations. Rather an advanced 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 advanced reading.

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.

An inexpensive apparatus for demonstrating magnetic levitation, by Carlos Saraiva, The Physics Teacher 45, 311 (2007)
Demonstrates the levitation by eddy currents (a bit like the Maglev trains)
Measuring the interaction force between a high temperature superconductor and a permanent magnet, by S. O. Valenzuela, G. A. Jorge, and E. Rodríguez, Am. J. Phys. 67, 1001 (1999)
An experimental setup for measuring the vortex pinning strength of a superconductor. The HTK experiment “Measuring the pinning” is based on this article.

Levitation of a magnet over a superconductor, by P. J. Ouseph, the physic teacher 28, 205 (1990)
Describes type I and type II superconducting levitation.

Understanding stable levitation of superconductors from intermediate electromagnetics, by A. Badía-Majós, Am. J. Phys. 74, 1136 (2006)
Simulates the pinning of vortex using Maxwell equations and a modified Ohm’s law.

Web resources

Project results

mosem.eu
youtube.mosem.eu
simulations.mosem.eu
animations.mosem.eu
online.supercomet.eu

Superconductivity

superconductivity.eu
superledning.no
vulgarisation.fr

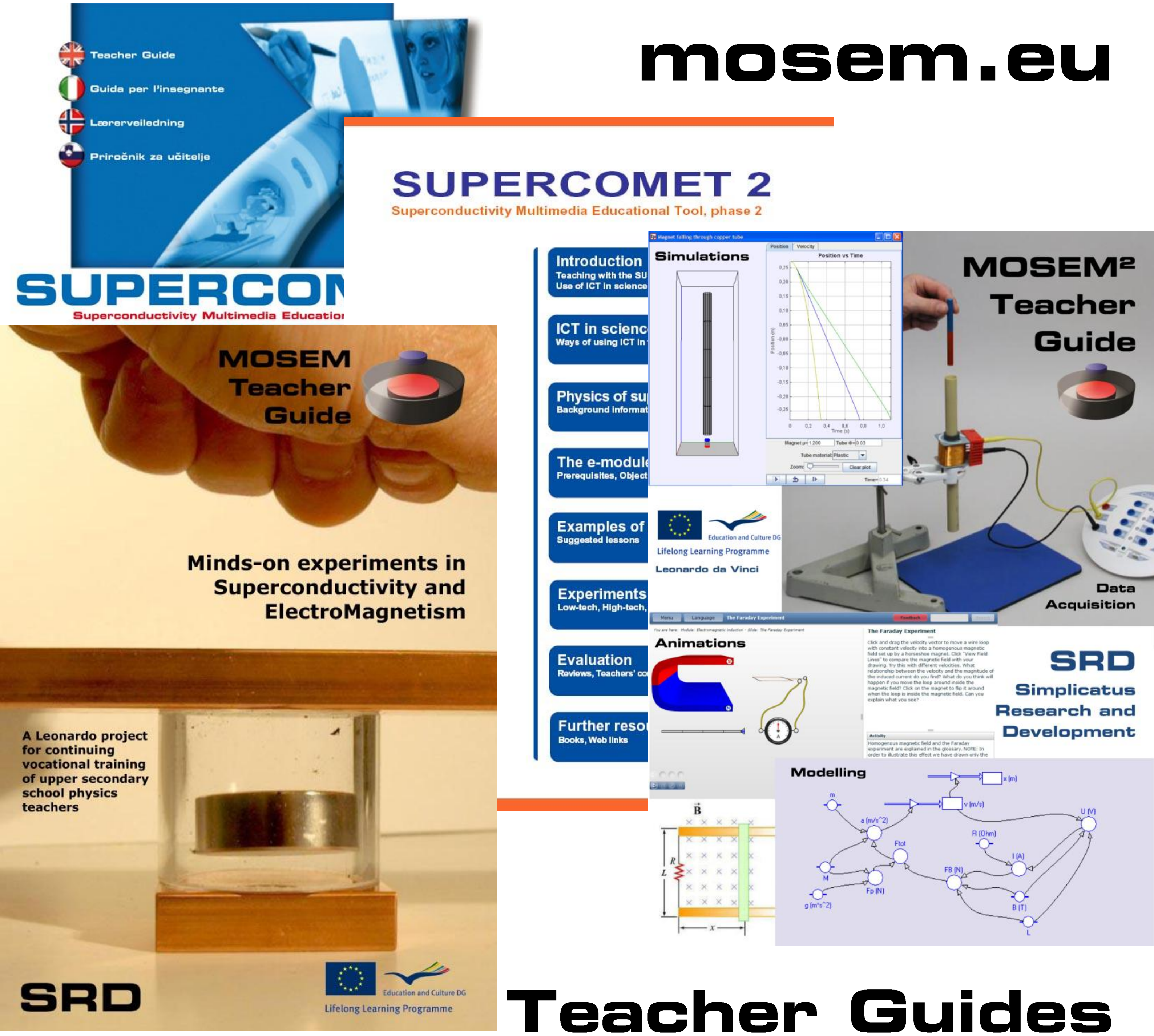
Project community

forum.mosem.eu
twitter.mosem.eu
linkedin.mosem.eu
facebook.mosem.eu
media.mosem.eu
supercomet.eu

Professional development

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

mosem.eu



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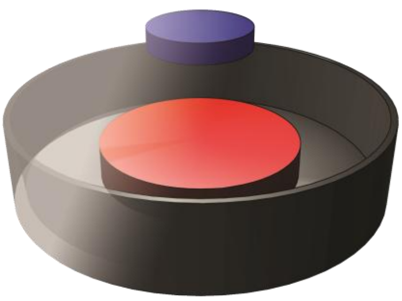

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