SUPERCOMET 2

Superconductivity Multimedia Educational Tool, phase 2

Teacher Guide

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SUPERCOMET 2 – www.supercomet.eu

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Education and Culture

Leonardo da Vinci

The SUPERCOMET 2 Project aimed to:

- Expand an international partnership committed to renewal of physics teaching across Europe.
- Establish firm connections with existing organizations for physics educators, researchers in physics education, curriculum authorities and policy makers.
- Develop a concept for and actual products for teacher training in physics education that may be put to use immediately, simultaneously allowing for expansion in both subject and scope.

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SUPERCOMET online e-modules:

www.supercomet.eu

Introduction

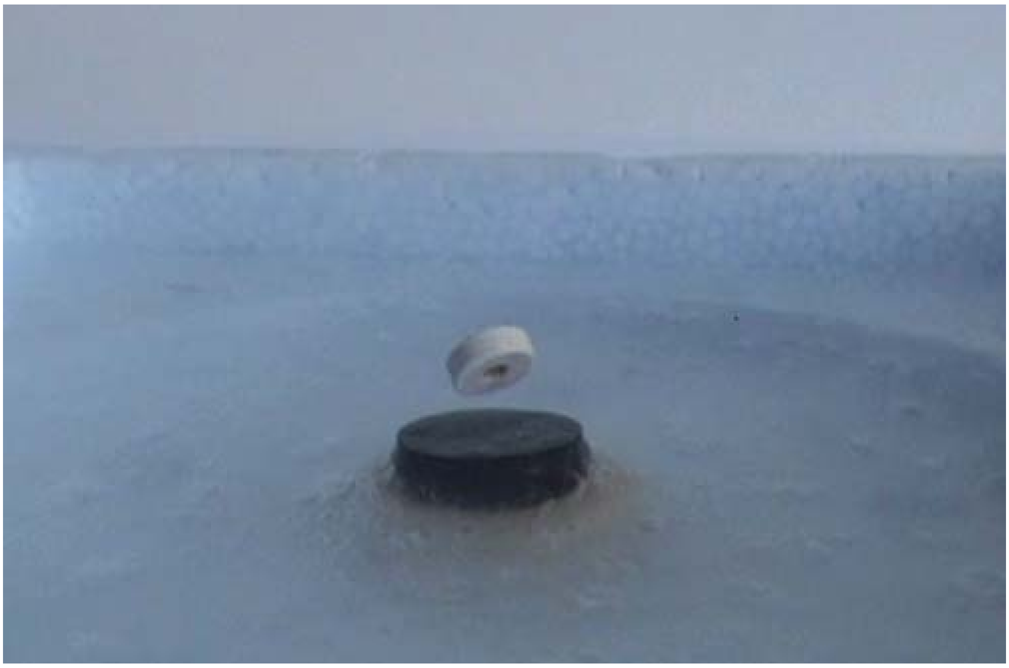
SUPERCOMET – e-modules and Teacher Guide

Based on a pedagogical view of learning of pupil-active exploration, the SUPERCOMET 2 project developed a computer application with e-modules combining graphics, animations, video, explaining text, suggested activities and a glossary to make parts of the physics curriculum in upper secondary schools more engaging and accessible. This teacher guide and a comprehensive teacher seminar support and explain how to use the e-modules in teaching. The teacher seminar goes into more detail on the experimental activities and teaching methods for the pupil-active learning promoted by the project.

Learning Objectives for the e-modules

The SUPERCOMET e-modules provide an introduction to superconductivity with suggested activities, theories upon which its discovery is based (including magnetism, electrical induction and conduction), and its history. Based on work with the SUPERCOMET materials, pupils will be able to

1. argue how a theory is related to evidence
2. explore possible uses of the phenomena
3. explore technological implications of a new discovery
4. describe how scientists gain and interpret data
5. describe how science and technology uses new ideas
6. communicate scientific ideas to different audiences
7. ask questions of themselves about physics and how it is related to everyday life
8. suggest some connections between different fields of physics



Aims of the Teacher Guide

The teacher guide is intended to outline the pedagogical rationale for using SUPERCOMET and suggest effective ways of using it in the classroom, as part of everyday teaching, in stand-alone mode and in combination with practical demonstrations and multimedia tools. It gives information about the physics of superconductivity and shows possibilities for evaluation of the work with SUPERCOMET.

Intended audience

The intended audience of the SUPERCOMET materials is physics teachers of upper secondary school and their pupils, who will directly benefit from the new materials and methods presented.

SUPERCOMET – the application

The SUPERCOMET learning application consists of self-contained e-modules and a set of other useful navigational, teaching and information resources set out as in the site map below:

Navigation

- Main menu
- Languages
- Help
- Glossary
- FAQ

Main menu – e-modules

- Magnetism
- Electromagnetic induction
- Electrical conduction
- Introduction to superconductivity
- Applications of superconductivity
- Activities with superconductors
- History of superconductivity
- Superconducting materials
- Explanation of superconductivity

Search tool

Animations

- Textual resources
- Bookmark tool
- Activities
- Videos
- Photos
- References
- Links

A quick start guide

1. When you search for a special topic (e.g. electrical resistance), browse through the relevant module contents listed in the teacher guide. Check page **Feil! Bokmerke er ikke definert.** to see if there are any ready-made teaching plans you could adapt for your teaching.

2. Go to **www.supercomet.eu**, click to start the online e-modules and familiarise yourself with the navigational structure.

3. Using the Main Menu, go to the module most appropriate to the topic you are teaching and familiarise yourself with it. Either use the SUPERCOMET e-modules as suggested in the teaching plan you have found in the guide or write a lesson plan of your own.

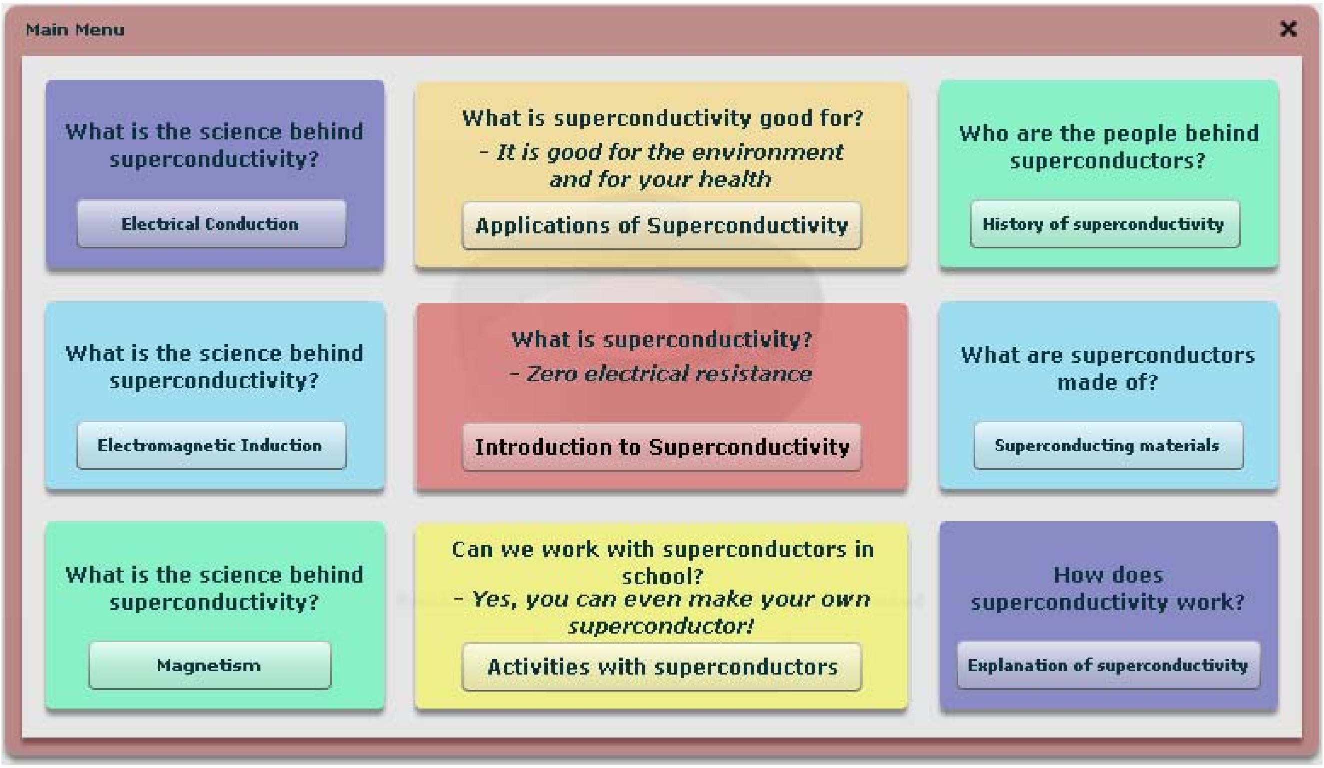
4. After the lesson, evaluate how it went. You might want to share your work with other teachers by logging on to the Physible online community at **www.physible.eu**.

5. More information on Minds-On Experiments using simple materials to demonstrate fascinating electromagnetic phenomena connecting with the contents of the e-modules can be found at **www.mosem.eu** – in time you will be able to order packages of the necessary materials there.

How do I start using the SUPERCOMET online e-modules?

Go to **www.supercomet.eu** and click the link to the online e-modules at **online.supercomet.no**.

From the Main Menu, go to the module most appropriate to the topic you are teaching and familiarise yourself with it. Either use the SUPERCOMET e-modules as suggested in the teaching plan you have found in the guide or write a lesson plan of your own. The pupils should not just browse the modules passively, but use them as a resource in an active exploration of the topic they are studying.



What is the science behind superconductivity?
Electrical Conduction

What is superconductivity good for?
- It is good for the environment and for your health
Applications of Superconductivity

Who are the people behind superconductors?
History of superconductivity

What is the science behind superconductivity?
Electromagnetic Induction

What is superconductivity?
- Zero electrical resistance
Introduction to Superconductivity

What are superconductors made of?
Superconducting materials

What is the science behind superconductivity?
Magnetism

Can we work with superconductors in school?
- Yes, you can even make your own superconductor!
Activities with superconductors

How does superconductivity work?
Explanation of superconductivity

Recommended specifications for computer system and browser

These requirements are necessary for working with the SUPERCOMET online application:

Minimum system specifications

- Microsoft Windows 2000, XP or Vista (**PC**)
- MacOS X 10.1.x (**Macintosh**)
- Red Hat® Enterprise Linux (RHEL) 3 update 8, RHEL 4 update 4 (**Linux**)
- 1,2 GHz processor
- 128 MB RAM (or graphics memory)
- 16-bit colour
- 1280 x 1024 screen resolution

Browser specifications

- Optimized for Firefox 2.0.x and later
- Needs Adobe Flash Player version 9, see www.flash.com for free download and further details
- Other compatible browsers:
  - Internet Explorer
  - Netscape
  - Mozilla
  - Opera
  - Safari
  - SeaMonkey

How do I find my way around the SUPERCOMET application?

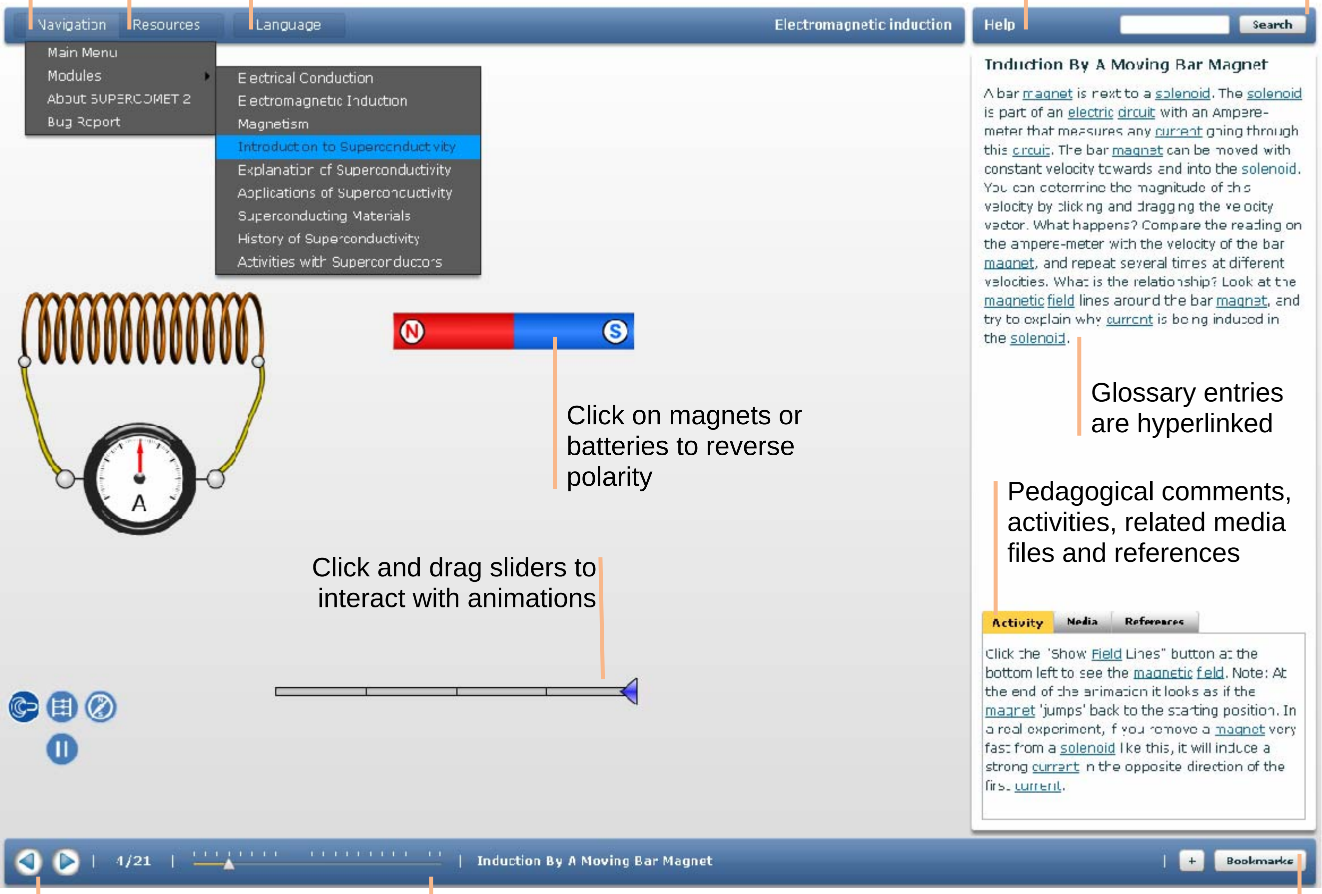
Main Menu or jump to other modules

Glossary, FAQ, all media files and references, other resources including this Teacher Guide.

Change language

Help with explanation of the navigation and interface

Search for keywords in all modules, FAQ and Glossary



Induction By A Moving Bar Magnet

A bar magnet is next to a solenoid. The solenoid is part of an electric circuit with an Ampere-meter that measures any current going through this circuit. The bar magnet can be moved with constant velocity towards and into the solenoid. You can determine the magnitude of this velocity by clicking and dragging the velocity vector. What happens? Compare the reading on the ampere-meter with the velocity of the bar magnet, and repeat several times at different velocities. What is the relationship? Look at the magnetic field lines around the bar magnet, and try to explain why current is being induced in the solenoid.

Click the "Show Field Lines" button at the bottom left to see the magnetic field. Note: At the end of the animation it looks as if the magnet 'jumps' back to the starting position. In a real experiment, if you remove a magnet very fast from a solenoid like this, it will induce a strong current in the opposite direction of the first current.

Click on magnets or batteries to reverse polarity

Glossary entries are hyperlinked

Pedagogical comments, activities, related media files and references

Click and drag sliders to interact with animations

You can use the controls to interact with the animations. In addition to the navigation buttons, back, next and pause, you can hide/show magnetic or electrical fields, and add small compasses to probe magnetic fields.

The progress bar can also be used for navigating back and forth in the module.

You can bookmark a page that you would later like to come back to. You can "make your own module" this way, by adding pages in the sequence you prefer and use this as a playlist.

Teaching with the SUPERCOMET materials

Frequently asked questions

Q: Superconductivity is not in the curriculum, so why would I teach it?

A: Superconductivity can be used as an engaging way to teach pupils about the structure of matter, electricity, magnetism and electromagnetic induction. See 'Superconductivity can be used as an exciting way to teach many physics concepts' on p. 9 for more information.

Q: I teach children under 16. Can I use superconductivity in my teaching?

A: Yes – simple demonstrations of superconductivity can be implemented for younger pupils.

Q: I don't have time to run through all of the e-modules. Can I use part of them?

A: Yes – although you can work through the e-modules from start to finish, it is possible and perhaps even better to use different parts of the content (text, graphics, animations) on a stand-alone basis. Use the search function to find relevant materials for the topic you are currently teaching. See also the module descriptions on p. 29 for more information.

Q: I find some of the animations in the e-modules very useful. Can I use them in materials my pupils or I create, such as in web pages or PowerPoint presentations?

A: The SUPERCOMET materials are copyrighted and may only be used for educational purposes according to the purchase license. See ***www.supercomet.eu*** *for more information.*

Q: Why should I use the e-modules instead of live demonstrations, which my pupils enjoy?

A: Use it as well as, rather than instead of the live demonstrations. Pupils can then use the e-modules to check the results they obtained. In some cases, the e-modules can be used to demonstrate things which would be impossible in a school laboratory. See 'ICT in Science Teaching' on p.13 for more information on how ICT can help pupils learn.

Q: Could I replace practical lab lessons with the SUPERCOMET e-modules?

A: Not really – research suggests that pupils benefit more from learning with simulations alongside 'real' practical demonstrations.

Q: Are there any lesson plans or other teaching materials that I could use?

A: Yes – this teacher guide includes a number of useful teaching materials and suggestions for learning activities. See 'Examples of activities' on p. 48 and 'Experiments – teacher seminar' on p. 70 for more information. Further resources are available on the Internet, see list on p. 105.

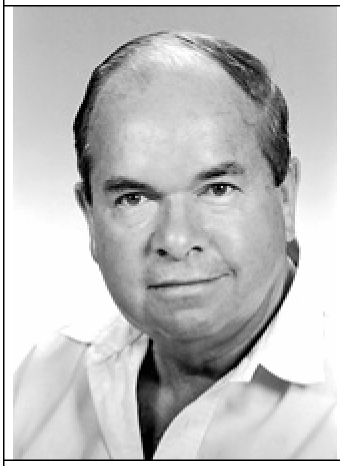
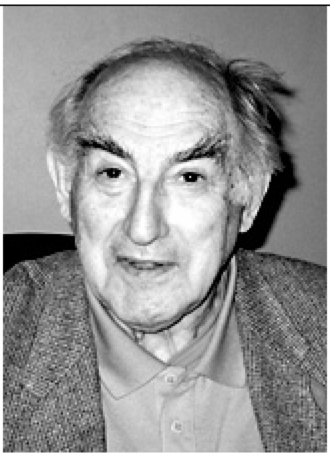
Q: I have developed some superconductivity materials I would like to share. What should I do with them?

A: The SUPERCOMET 2 project started work on an international online community of teachers sharing materials for teaching electromagnetism and superconductivity, and this work is carried on in the MOSEM and later projects. See ***www.supercomet.eu*** *for more information.*

Superconductivity can be used as an exciting way to teach many physics concepts

Superconductivity can be used as a context in which to teach
- Magnetism
- Electrical induction and conduction
- The relationship between temperature and resistance of metalic conductors
- The effect of temperature on materials in terms of lattice vibrations

By using superconductivity as the context for learning about concepts such as temperature and magnetism, pupils can immediately link the theory to their lives, making their learning more relevant and exciting.

<table>
<tr><td colspan="3"><i>The Nobel prize in Physics 2003: "for pioneering contributions to the theory of superconductors and superfluids"</i>
<i>http://nobelprize.org/nobel_prizes/physics/laureates/2003/index.html</i></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td><i>Alexei A. Abrikosov</i></td><td><i>Vitaly L. Ginzburg</i></td><td><i>Anthony J. Leggett</i></td></tr>
</table>

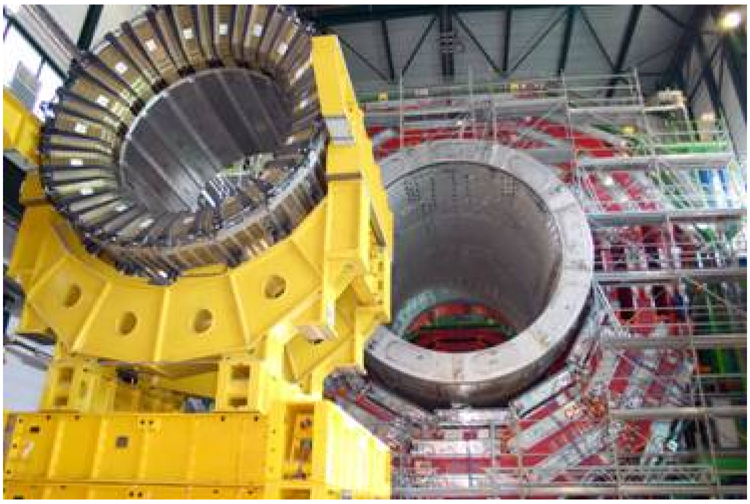
Superconductivity is cutting-edge

- As recently as 2003 the Nobel Prize was awarded to superconductivity researchers
- Superconductivity research is currently taking place in most universities, in many hi-tech companies and research institutions.

Superconductivity theory is used in many exciting modern applications

- Medical Imaging System (Magnetic Resonance Imaging – MRI)
- Maglev (Levitating) trains
- Magnetic shielding
- Particle accelerators
- Advanced mobile telephony
- SQUID magnetometer (ultra-sensitive detector of magnetic fields)
- Power transmission cables
- Energy storage devices

2003 First commercial Maglev train: Shanghai Transrapid
http://en.wikipedia.org/wiki/Image:Shanghai_Transrapid_002.jpg

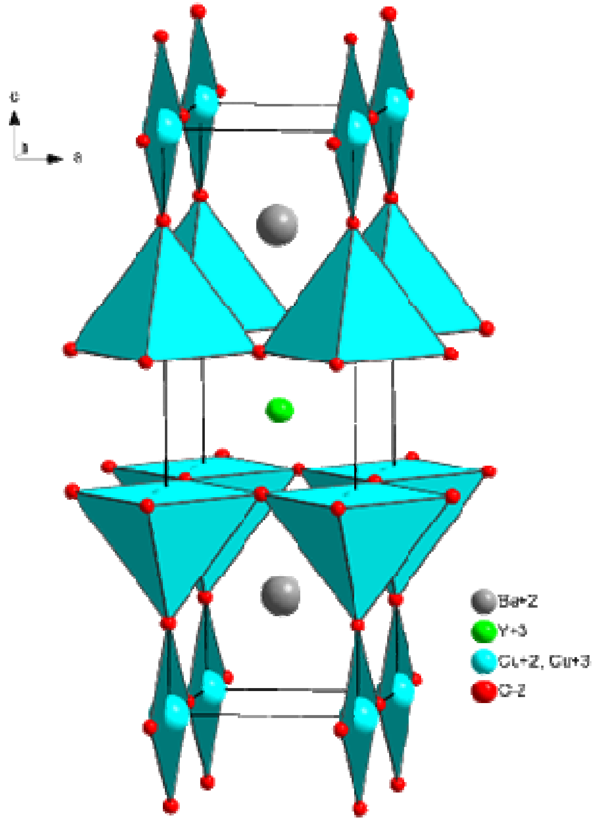


Superconducting solenoid, a part of the detector CMS within the LHC (Large Hadron Collider) at CERN
http://en.wikipedia.org/wiki/Image:HCAL_Prepared_for_insertion.jpg

Sagittal slice of a Structural MRI scan of a human head.
http://en.wikipedia.org/wiki/Image:MRI_head_saggital.jpg

Superconductivity opens the door on what physicists actually do

- Hundreds of physicists across the world are currently involved in superconductivity research.
- A total of 12 researchers across the world have been awarded Nobel prizes (in 1913, 1972, 1973, 1987 and 2003) for superconductivity-related work.



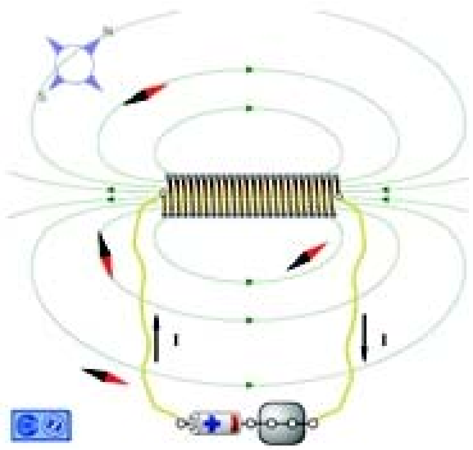
The unit cell of YBCuO, a high-temperature superconductor
http://de.wikipedia.org/wiki/Bild:YBCO.gif

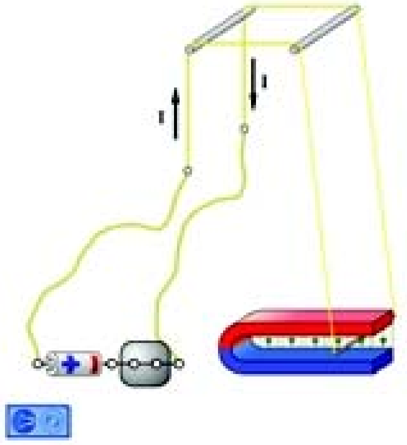
SUPERCOMET animations bring physics to life and help pupils learn

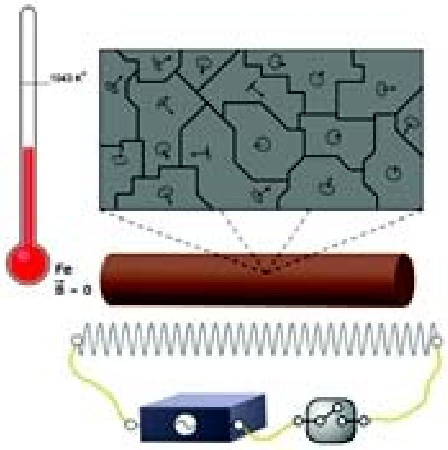
Whilst the SUPERCOMET e-modules include a wide set of textual reference materials, links, glossary, images, video clips of demonstrations and quizzes which together all contribute to providing an excellent superconductivity teaching resource, the most important feature of SUPERCOMET is the large number of interactive animations of physical processes that it provides.

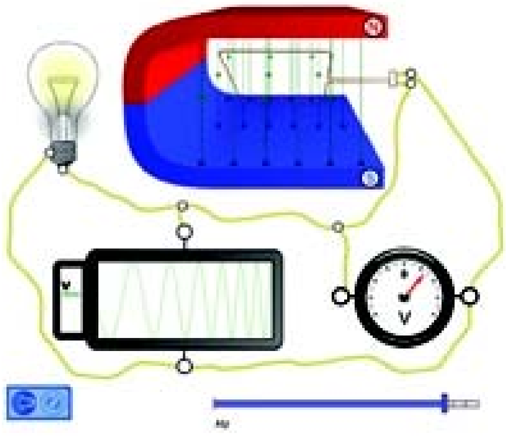
The screenshots on the next page show a small selection of the many interactive animations found in the online e-modules.

Screenshots of some interactive animations from the CD-ROM







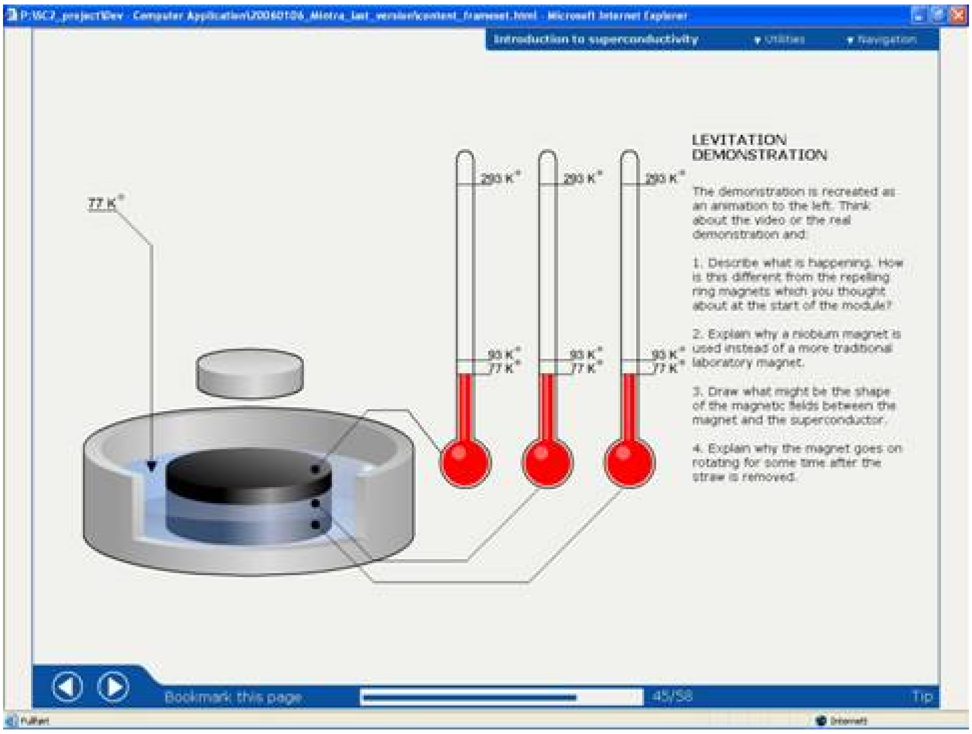


How animations can help learning

- Virtual labs can provide pupils with access to a number of experiments that would otherwise be impossible for them to experience in a normal classroom, for reasons of safety, or because the effects are too fast, slow or small.
- By interacting with animations, easily altering factors and examining the effects of these changes, pupils can gain insights that might otherwise be hidden by noise and the difficulties of practical experimentation.
- If used in combination with experiments in the real world, animations can help pupils understand the relationship between models and reality, and thus come to an understanding scientific work.
- Animations make learning science more enjoyable and appealing to pupils.
- Animations have been shown to be effective in illustrating the complex functional and procedural relationships so often found in physics learning.
- By adding a conceptual interpretation to the simulations of what is a stripped-down version of reality, animations can help pupils link conceptual models with real-life phenomena.
- Animations provide learners with still and moving images, both of which are essential to understanding and memorizing scientific concepts.
- Animations remove the noise found in live experiments, thus allowing pupils to construct models of physical phenomena more easily.
- Interactive animations of physical concepts can allow pupils to test and refine their own models of new phenomena.
- Appropriate animations can help learners to decode text.
- Animations allow the pupils to be more active in their learning, thus relying less on their teacher as the main source of knowledge.

Teaching note
There is evidence that pupils may take simulations and animations too literally, and thus develop an over-simplified understanding of the 'messy' physical phenomena they represent (see, for example, Wellington, 2004). For this reason, it is important that animations and simulations are used, if possible, in conjunction with real experiments, and that the teacher takes an active role in helping pupils build an understanding of the nature of models and their role in science.

The new MOSEM project is developing Minds-On Experimental Equipment Kits with activities related to the e-modules precisely for making it easier to achieve teaching with such pupil-active learning. See **www.mosem.eu** for more information.



LEVITATION DEMONSTRATION

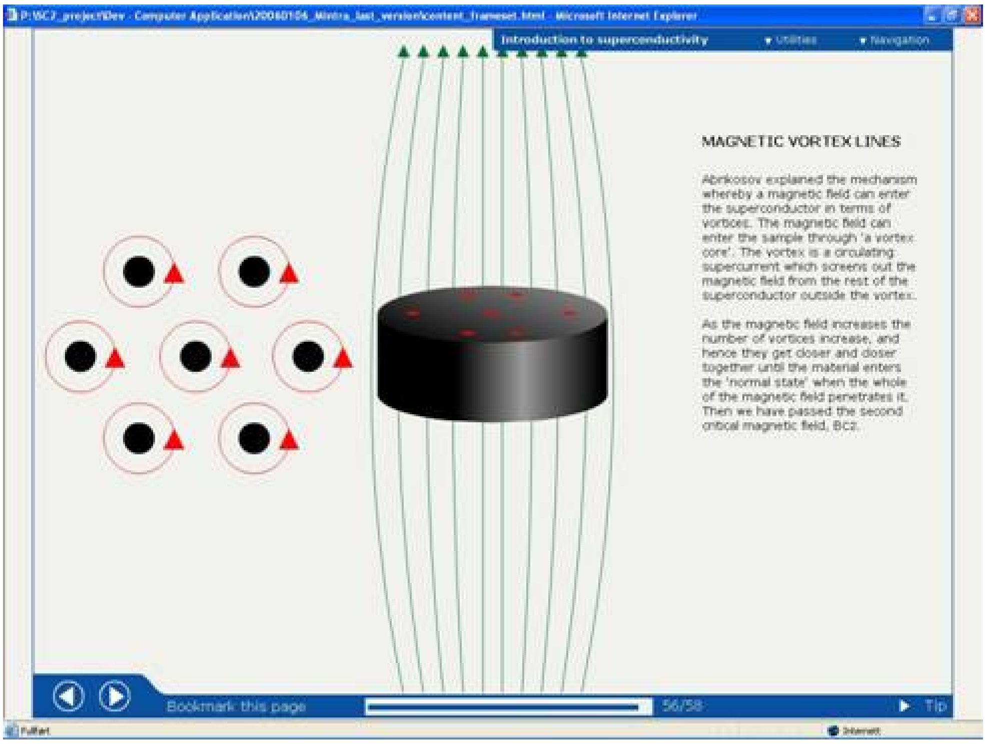
The demonstration is recreated as an animation to the left. Think about the video or the real demonstration and:

1. Describe what is happening. How is this different from the repelling ring magnets which you thought about at the start of the module?

2. Explain why a niobium magnet is used instead of a more traditional laboratory magnet.

3. Draw what might be the shape of the magnetic fields between the magnet and the superconductor.

4. Explain why the magnet goes on rotating for some time after the straw is removed.



MAGNETIC VORTEX LINES

Abrikosov explained the mechanism whereby a magnetic field can enter the superconductor in terms of vortices. The magnetic field can enter the sample through 'a vortex core'. The vortex is a circulating supercurrent which screens out the magnetic field from the rest of the superconductor outside the vortex.

As the magnetic field increases the number of vortices increase, and hence they get closer and closer together until the material enters the 'normal state' when the whole of the magnetic field penetrates it. Then we have passed the second critical magnetic field, Bc2.

ICT in science teaching

How to use information and communications technology (ICT) in science teaching

Main forms of ICT relevant to school physics

Many forms of ICT can be useful in the physics classroom or laboratory. Used in combination with teaching and student-centred activities, they have the potential to transform student learning. The list below includes some of the technologies listed by Osborne & Hennessy (2003).

Data capture systems

Data capture systems, which include data logging hardware plus data processing and interpretation software, help pupils engage in and interpret the results of practical physical experiments and develop an investigative approach to science. A data logging device may be used both in an off-line setting and as a computer interface. The off-line or field setting allows measurements to be performed without the necessity of being connected to a computer.

Data loggers such as ***CMA ULAB*** (www.cma.science.uva.nl), ***TI CBL2*** (education.ti.com) or ***Data Harvest*** (www.data-harvest.co.uk), take and store repeated readings from a series of sensors over a period of time to analyse such data as light, temperature, sound, conductivity, voltage and motion. Each modern data logger has its own simple graphing tools to get an immediate, first impression. Having taken readings, the data logger can be connected to a computer or P.D.A. to display and analyse the data in more detail.

Data video measurement

Data Video enables the analysis of the motion of real objects and events which happen outside the classroom. Video analysis software allows a user to collect position and time data from digital video The events can be rather ordinary, every day events such as bicycle rides, soccer kicks, basketball shots, amusement-park rides, or more unusual like car crashes or jumps on the Moon. The video measurements can be performed on digital videoclips (format: AVI, MOV or MPG), or on single images (format: BMP, GIF or JPG).

During the video measurements position and time data are collected in the selected video frames manually by clicking or automatically by tracking a moving object e.g. a ball, a head. The video points collected this way can serve to calculate the locations of other points e.g. the center of mass. During measurements on a single image, position data, or position and time data for stroboscopic images, are collected by clicking points of interest in an image. The video/image data can be displayed in a diagram or table and can be used for further analysis and processing.

Digital videoclips for use in Data Video can be found on the Internet or readily created by webcam or digital camera. Video analysis software as found in the program ***Coach 6*** (www.cma.science.uva.nl), also provides possibilities for capturing and editing videoclips from digital sources, such as webcams. Editing options include:
- adjust brightness and contrast
- rotate and flip
- place text annotations
- perform perspective correction.

Information systems

This category includes the Internet, CD ROMs, electronic encyclopaedia etc. It provides a source of information on which pupils can draw in the course of their own learning. For example, they could use the SUPERCOMET e-modules – or an online encyclopaedia – to find out about the Nobel prizes awarded to superconductivity researchers.

Modelling tools

A modelling environment is a software tool that enables learners to create *executable* models of science phenomena and allows for the solution and visualization of science problems in a digital way. In this respect, paper can be considered an *inert* medium in contrast to the computer as an *active* medium that can be manipulated. Many authors consider modelling an (or even *the*) essential aspect of the scientific approach of a problem, illustrated by the slogan *Science is the name, modelling is the game.* So, modelling in science may be both goal or intrument.

A modelling environment is used to create and analyze models of biological, chemical, physical, economical, social and ecological systems. It is tool-like in the sense that it provides the user with a powerful set of possibilities, but it does not tell the user what to do with these possibilities.
There are **several modes** of constructing and viewing models: Graphical mode, Equations mode or Text mode.

The **Graphical mode** is frequently coined System Dynamics Modelling software such as Stella (www.iseesystems.com), PowerSim (www.powersim.com) or Coach 6 (www.cma.science.uva.nl), based on the stock-flow approach developed by Prof. Jay. W. Forrester at MIT in the early 1960s. System dynamics is a methodology used to understand how systems change over time. Such models can be of a much greater complexity and carry out more simultaneous calculations than human mental models.

The **Equations and Text modes** are text-based modes, which use a textual representation of the mathematics hidden behind models. The model of differential equations can be solved by different numerical iteration methods like Euler or Runge-Kutta, circumventing the rather advanced mathematics that would otherwise be needed to solve realistic yet complex problems. Also spreadsheets like Excel can be used for creating models. Allowing pupils to construct and test their own models of processes can be a powerful learning tool.

Multimedia Software

Multimedia software such as that provided by SUPERCOMET usually includes text, video and audio clips, spoken explanations, graphics and animations, tutorials, interactive activities, slide shows and glossaries. Particularly useful for physics teaching are the virtual laboratories, which allow pupils to carry out, virtually, experiments that they might not otherwise be able to conduct in the classroom. It also allows them to compare the data they obtain in real-life experiments with model-based data. Multimedia software can be used for demonstrating phenomena (e.g. magnets levitating above cooled superconductors) and/or simulating processes in ‘virtual experiments’ (e.g. the relationship between the speed of movement of a copper wire through an electric field, and the resulting voltage).

Internet/Intranet Publishing and presentation tools

Pupils can use word processing software or multimedia presentation packages (e.g. Dazzler at www.dazzlersoft.com) to prepare their own accounts of physical phenomena they have been learning about during the course of a real or virtual experiment for presentation to others. These accounts can form part of a portfolio of work. Such accounts could also be developed using html editors such as Dreamweaver (www.macromedia.com) and posted on a school intranet, or even on the Internet, as a public record of the pupils’ learning. There are many sites which host a web page at no cost – www.geocities.com or www.webspawner.com are two good examples.

Digital recording equipment – still and video cameras

Teachers – and pupils – can use digital cameras and videocams to record experiments they have worked on, or to take photographs that can be used for revision (or teaching) or which pupils could include in their own work.

Computer projection technology

Computer projection technology is an important element in physics teaching. It can be used to make public and thus visible to all that which may be available only on a single computer. Data projectors and screens, large monitors or TVs can be used alongside all the above technology to teach or perform demonstrations, and to keep a record of them. Even more helpful, interactive whiteboards allow pupils to interact with the material being presented, whilst screen monitoring and sharing software (e.g. AB Tutor Control, www.abconsulting.com) enables a tutor to share the screens of pupils with the whole class, thus allowing, for example, for comparison between results obtained by different pupils and a model from SUPERCOMET. Used together, screen sharing technology and interactive whiteboards can allow for a full, common record to be made of an experiment.

Why use ICT in Physics Teaching?

The use of ICT across the science curricula in Europe has been a statutory requirement since the beginning ninties. A recent literature review (Osborne & Hennessy, 2003) has argued that ICT has the potential to really transform teaching and learning in the science classroom. Benefits they note include:

ICT can help pupils to work faster and frees them up from labour-intensive tasks

- The use of ICT (particularly data logging, handling and graphing) can speed up the tedious and error-prone tasks such as taking multiple and complex measurements, working out difficult formulae and plotting graphs.
- It is possible to capture and compare larger numbers of results, including across classes and time.
- ICT improves the productivity of pupils and the quality of work they produce.
- Interactive computer simulations can prevent pupils – and teachers – wasting time setting up equipment.
- As well as being faster than manual procedures, ICT-based ones are more accurate and yield less ‘messy’ data, which can therefore illustrate phenomena more clearly.
- Pre-selected links in electronic worksheets and interactive activities can save pupils time in locating relevant resources.
- ICT frees up teachers and allows them to spend more time working with pupils, helping them to think and analyse their data, and to compare their findings with those of others.
- Real-time data displays can be used as the basis of classroom discussion and can allow a teacher to instantly demonstrate the link between a phenomenon and its model, even when there are multiple variables.
- Using computer modelling and simulation allows pupils to investigate far more complex models and processes than would be possible in a classroom.
- As time is released from laborious tasks, pupils have more time to think about the phenomena they are examining.

Broadening learning and bringing it up-to-date

- ICT and the Internet give pupils access to a broader range of up to-date tools and information resources. This allows for school teaching and learning to be more authentic and current than is possible with textbooks alone.
- Pupils can make links between what they are learning and the ‘real world’.
- Good pupils are able to use the resources provided to learn more than the teacher – or curriculum – had planned.
- Simulations, animations and virtual laboratories allow pupils and teachers to observe and take part in demonstrations that would otherwise be impossible for reasons of cost, safety, time or equipment.
- Virtual experiments can be repeated as many times as is necessary for the learner, something which can rarely be done in a real practical.

ICT encourages pupils to explore and experiment

- Use of graphing and modelling tools as well as interactive simulations which offer immediate feedback encourages pupils to work in a more experimental, playful manner, investigating relationships and testing, refining and re-testing ideas of their own.

- Viewing a graph develop or model unfold on a screen makes the Predict – Observe – Explain teaching technique work particularly well.
- Interactive computer models and the fast presentation of data allowed through using ICT such as data logging systems, encourages pupils to ask exploratory (“what if...”) questions and to test the answers to these questions by devising and carrying out further virtual activities.
- Because ICT is interactive and dynamic in a way a printed text cannot be, its use (e.g. spreadsheets and modelling software) develops in the pupils an iterative approach to learning.

ICT puts the spotlight on the important, overarching issues

- Pupils are better able visualise physical processes and to relate different variables in qualitative or numerical relationships
- Attention can be focused on the issue/concept being examined rather than on minutiae
- The abstract and otherwise difficult to perceive features of physical processes (e.g. current and magnetic fields) are highlighted.
- Pupils can grasp concepts more quickly and easily, they can formulate new ideas faster and transfer them between contexts more smoothly.
- When a graph evolves on the screen in real time, pupils’ attention is drawn to what is happening with the data.
- By using computer data analysis and interpretation systems, pupils are better able to focus on relationships between variables rather than just on the individual points that make up the graphs.

Encouraging self-sufficiency as well as collaborative working

- Using ICT to explore and experiment with physics phenomena gives pupils more control over their own learning and thus encourages them to take a more active role in it.
- Pupils carrying out research or practical activities using ICT may work more (but not completely) independently of the teacher.
- “Independence” does not mean pupils working alone. Peer collaboration between pupils working together on tasks, sharing their knowledge and expertise, and producing joint outcomes is becoming a prevalent model for the use of educational technology.

Improving motivation and engagement

- There is ample evidence that pupils find working with ICT more motivating than working in alternative modes.
- ICT can vastly improve the quality of presentation of student work, as it enables pupils to create multimedia resources themselves.
- Pupils are more likely to actively participate in and persevere with laboratory activities, because ICT offers a novel way of learning, but also because ICT eliminates some of the more boring tasks, whilst the immediacy and accuracy of the results obtained can itself be motivating.

Ways of using ICT in the classroom

One teaching scenario would involve a series of real-life experiments, each of them linked to data logging equipment with real-time graphing software, connected to an overhead projector and network running screen sharing software, from which pupils can download data for presentation to pupils in another country through the internet. These real experiments would be supplemented with a set of simulations such as those provided in the SUPERCOMET e-modules. All of the demonstrations could furthermore be videoed in real time, with the clips being available for student use.
Although having such a laboratory full of computers, whiteboards, digital video recorders, projection hardware and data logging equipment, with a connection to the Internet might seem to be the ideal situation, schools often cannot afford this level of resourcing. This is not always a bad thing: alternative methods of working, which may call for the active engagement and collaborative working of pupils can be very effective. Barton (2004) suggests the following solutions:

Demonstration

Real-life demonstrations using conventional equipment (e.g. mercury thermometers) carried out alongside data logging and real-time graphing, followed by interactions with simulations can be very powerful, particularly if teachers have asked pupils to make predictions (e.g. sketch graphs) before the start of the demonstration. You could use this option for experiments where you do not want pupils to handle expensive and fragile sensors or hazardous materials such as liquid nitrogen. You can use graphs developed through the demonstrations – and video recordings of the demonstrations themselves – in revision, helping pupils revisit earlier experiments and demonstrations.

Using data loggers as well as conventional equipment

When there is more than one set of data logging equipment available, but not enough for the whole class, then there are other ways of working. The teacher and/or a group of pupils could collect data using the data loggers, whilst the rest of the class uses conventional laboratory equipment. Results could then be compared. Data logging equipment can also extend what is possible using conventional equipment, for example by allowing for the recording of data over periods that extend beyond a classroom period.

Circus of experiments and ‘dip-in-and-out’ lessons

If there is a limit on the data logging equipment and/or simulation software (e.g. the SUPERCOMET animations) available to a class, you can always use them as part of a ‘circus of experiments’ or as a ‘dip-in-and-out’ lesson. A circus of experiments requires pupils to move around the room from one practical activity/experiment to the next. You could, for example, put on a circus of short experiments on electromagnetic induction, some using real magnets, copper wire and galvanometers, others using SUPERCOMET. A dip-in-and-out lesson is similar, but here the main focus of class activity is a non-practical activity such as using the computer to collate, analyse and print data.

A ‘half-and-half’ lesson

You could use a half-and-half lesson if you only have enough computers for half of your pupils to work on them at any point in time. In this situation, you can get half the class working on computers whilst the other half work on a non-computer- based activity (e.g. a practical experiment). The two groups can then swap over half way through the lesson.

Using existing superconductivity resources

A Google search on Superconductivity will bring up almost five millions links!![1]
Therefore, you might expect, there is a large amount of material available, which you can bring to your teaching. This section gives you some pointers on how to find and evaluate that material. A Further Resources section has been provided at the end of this guide to help you in your choice of resources.

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[1] Search performed on 3 Sept. 2007

Some tips on searching for science-related information on the Internet[2]

It is usually not wise to allow pupils onto the Internet during class time to search for links to useful resources, as this can be time-consuming and the teacher has no way of controlling the quality of the resources that pupils find. It is often better to give the pupils a tried and tested list of URLs to follow. Selecting these without spending too long in the process is a difficult balance. The following questions may help:

- Is the information you are seeking likely to be found in an encyclopaedia? If it is, then visit an online encyclopaedia which may provide useful links as well as other information.
- Are you likely to find the information somewhere specific? For example, images of the Maglev train can be found at www.maglev-train.com, whereas information on the CERN Particle Accelerator can be found at www.cern.ch.
- If these fail, try a directory such as those available on ASE's site (www.ase.org.uk) or on www.superconductivity.org

If none of the above apply, you will need to conduct a search.

Tips on using a search engine

- Use different spellings to make sure you do not exclude US resources. For example, search on "behaviour" as well as "behaviour".
- Use variants of terms. For example, use "teaching materials" as well as "teaching resources."
- Use more than one search engine. Using a single engine does not constitute an exhaustive search.
- If using the Internet with children, the following websites may be helpful:
  – www.cybersleuth-kids.com
  – www.factmonster.com
  – http://kids.yahoo.com

Evaluating information

BECTA (http://schools.becta.org.uk) offer the following advice for evaluating websites:

- Does the content make its educational purpose explicit?
- Is the content accurate, up-to-date, reasonably comprehensive, objective or making clear its bias, relevant for the learner and does it use appropriate vocabulary?
- Is the interface intuitive, with well-organised material and clear navigation?
- Is the content meaningfully interactive, engaging the learner with key content or concepts and not merely creating virtual versions of activities that can take place easily and to better effect without computers, for example dice-rolling or simulating magnetic attraction?
- Does the resource provide support and give feedback?
- Does the resource enhance collaborative learning by encouraging learners to discuss problems, share information and ideas and reach group agreement?
- Is the resource technically stable?

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[2] Adapted from Fullick (2004)

Finding, adapting and sharing superconductivity teaching materials

Finding teaching materials

There is an increasing number of online databases and sources of teaching materials. Although few of these databases contain materials specifically about superconductivity, many contain ones on magnetism and electricity. Perhaps you could contribute your own?

- http://www.smete.org – Database of learning objects developed and maintained by the SMETE Open Federation.
- www.practicalphysics.org – website for teachers to share experiments.
- www.physics.org – the Institute of Physics has a number of links to superconductivity teaching materials

Adapting teaching materials

When you have found teaching materials, you should consider the following questions:

- Does the resource fit with the curriculum targets?
- Is the material pitched at the correct level for your learners?
- Is the resource presented in "chunks" that fit with your teaching schedules?
- How easy to use is the material?
- Do you have the necessary equipment and hardware to use the resource?
- Is the material accessible? (See www.techdis.ac.uk for advice)

It is likely that you will need to make some changes to the resource you find before it works for the pupils in your particular context.

Sharing materials

If you create new Superconductivity learning and teaching resources, why not consider sharing them with others? A new SUPERCOMET online community is being set up – watch www.supercomet.eu for more information.

Copyright issues

Always check carefully the Intellectual Property Rights of any materials you reuse. BECTA provides a useful guide in this area: (available at http://schools.becta.org.uk)

Physics of superconductivity

Heimo Latal, Graz (A)

Introduction / Phenomena

Starting point of the **discovery of superconductivity** was a discussion about the temperature dependence of the resistance of metals. According to the classical theory (*P. Drude and H.A. Lorentz*) there were two possibilities for the limiting case of zero absolute temperature:

- Electrons will condense at the atoms; the metal will become an insulator at T = 0 K.
- There is no condensation; the resistance goes to zero as the square root of T.

Experiments, however, revealed that neither of these two expectations were realized. After *Heike Kamerlingh Onnes* had been successful in liquefying helium (at 4.2 K) in 1908, the resistance of metals could be measured at very low temperatures with the result that it approached a finite value that depended strongly on the impurities. For very clean samples, therefore, the resistance should go to zero, as the observed temperature dependence could be associated with thermal motion of the atoms. In 1911 experiments with very clean mercury were performed with the result that indeed the resistance of mercury became immeasurably small, but unexpectedly the resistance went ***abruptly*** to zero (H. Kamerlingh Onnes was awarded the Nobel Prize for this discovery in 1913).

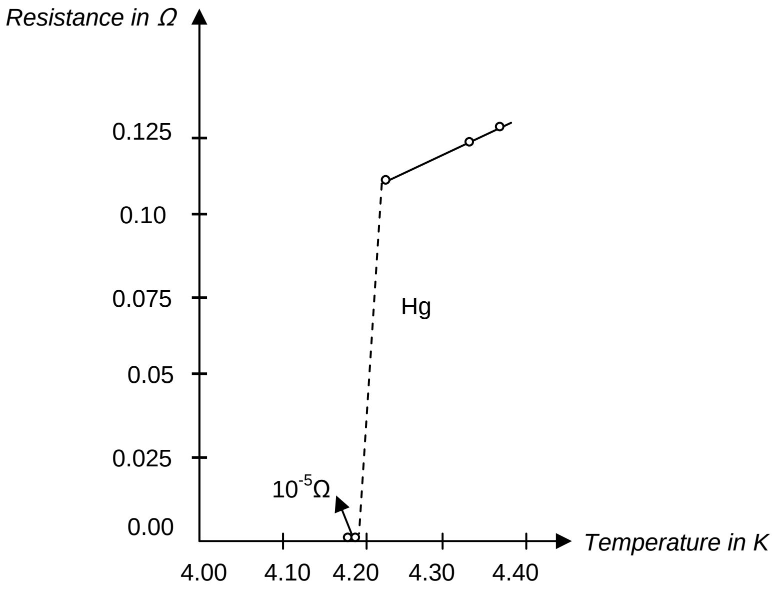


Fig. 1: Resistance of mercury: phase transition to superconductivity

Shortly afterwards it was discovered that above a **critical current density** the resistance became finite again.

Another phenomenon of superconductivity is of magnetic nature – the so-called "***Meissner-Ochsenfeld Effect***": superconductors exhibit the feature that they completely expel an applied magnetic field, independent of whether this field has been applied before or after the superconducting transition.

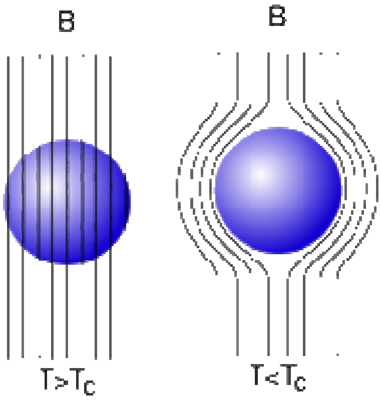


Fig. 2: Meissner-Ochsenfeld-Effect
http://commons.wikimedia.org/wiki/Image:EfektMeisnera.svg

A superconductor behaves therefore as a perfect diamagnetic material. But there exists a **critical magnetic field strength** above which superconductivity breaks down. Actually it is this magnetic behaviour that really characterizes a material as superconducting.
A fundamental theoretical description of these phenomena, however, was not achieved until 1957, when J. Bardeen, L.N. Cooper and J.R. Schrieffer were successful in developing a consistent quantum theory of superconductivity (**BCS-theory**). A manifestation of the quantum nature of superconductivity is the **Josephson effect** that led to the development of many innovative devices.
The magnetic behaviour described above is typical for so-called **Type I Superconductors**, usually represented by metallic elements. Later another kind of superconductors was found, called **Type II Superconductors**, being mostly alloys and compounds. They exhibit two critical magnetic field strengths: below the first one the material is in the Meissner state (like a Type I Superconductor), between the first and second one it is in a so-called mixed or Abrikosov state – after the 2003 Nobel prize winner -, and above the second critical field strength the material becomes a normal conductor again. The intermediate phase is characterized by the appearance of **flux vortices** in the material, each one carrying one unit of quantized magnetic flux ("**fluxoid**"). When the vortices are being held in place by defects ("**pinning**"), the material can tolerate quite high magnetic fields and is then called a "**Hard Superconductor**", such materials are therefore very useful for technical applications.
Between 1986 and 1993 a new type of superconductors has been discovered: the so-called "**High-Temperature (High-Tc) Superconductors**". These are characterized by very high critical temperatures, some well above the boiling point of liquid nitrogen (77 K). J.G. Bednorz and K.A. Müller were awarded the Nobel Prize in 1987 for their ground-breaking discovery of these superconductors. In the meantime the record critical temperature lies around 160 K.
Most of these materials are ceramics and the physics behind their superconductivity is still not clearly understood.

Electric Properties

Superconductivity, as the expression already indicates, describes the phenomenon that a piece of material becomes a perfect conductor with zero electric resistance, and that very abruptly below a certain temperature, the critical temperature T_c. Usually this happens at very low temperatures just above absolute zero. How justified is it to talk about a vanishing of resistance? At the time of the discovery the measuring accuracy was about 10^{-5}, today a decrease of the resistance at the onset of superconductivity can be measured to an accuracy of 10^{-14}. This can be done by monitoring the decrease of a current in a superconducting ring (Kammerlingh Onnes also employed this very sensitive method in 1914): First a bar magnet is inserted into the ring in the normal state then the ring is cooled below the critical temperature of the material. When the magnet is then removed, a current is induced in the ring. If this current decreases with time, then there certainly exists a resistance in the conductor; if not, an upper limit to the resistance can be determined.

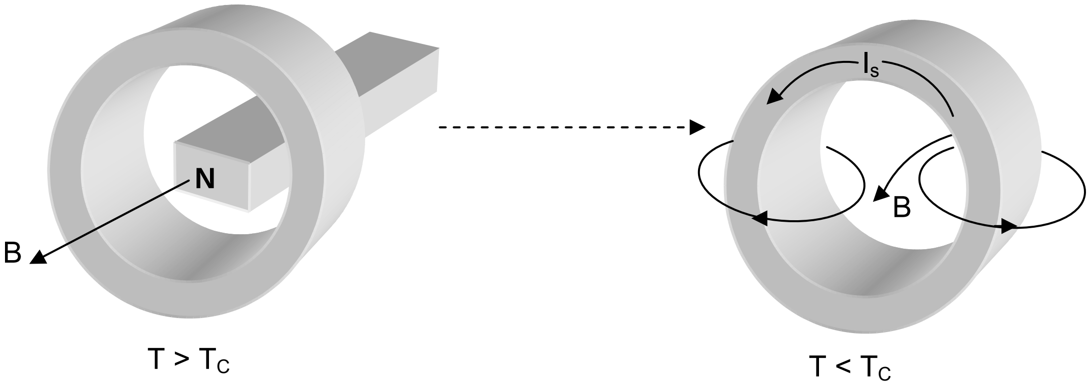


Fig. 3: Creation of a supercurrent in a superconducting ring: first the ring is cooled down, then the magnet is removed.

The low resistance of metals is connected with the observation that the charge transport is achieved by so-called free electrons in the material. Actually they are only quasi-free since they collide on their way with each other, leading to a so-called intrinsic contribution to the resistance (almost independent of temperature) and with the ions of the crystal lattice (actually elementary excitations of lattice vibrations, called phonons). The latter contribution now is strongly temperature dependent. Why should in a superconducting material suddenly the energy exchange between the conduction electrons and the lattice be forbidden? It took almost until 1930 for the idea to be established that superconductivity must be a macroscopic quantum phenomenon. Solids that are normally good conductors (like copper, silver, gold) often do not become superconducting, whereas many poor conductors can become superconductors. The reason for the latter observation lies in the strong electron-phonon-scattering, leading to a large resistance in the normal state, whereas the same effect is responsible for the superconducting mechanism. The existence of a limiting current density (critical current) that a superconductor can carry is related to this mechanism (see Section 4).

Magnetic Behaviour

In a magnetic field, superconductors behave quite differently from (even perfect) metallic conductors: a superconductor is a perfect diamagnetic material, the induced magnetization completely compensates an applied magnetic field – but only up to a critical field strength B_c (see fig. 4a).

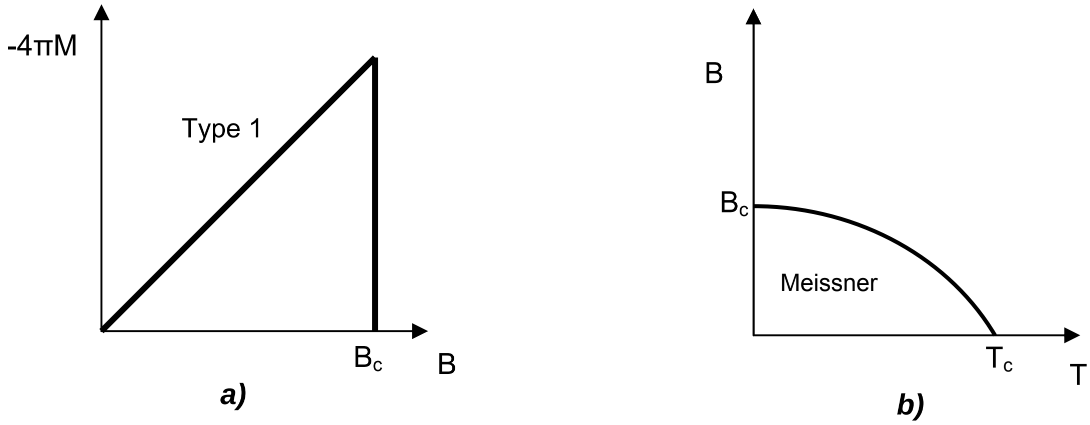


Fig. 4: a) Induced magnetization in a (Type I) superconductor as function of the applied magnetic field
b) Dependence of the critical magnetic field strength on temperature

In 1935 W. Meissner and R. Ochsenfeld discovered the effect (later named after them) that a magnetic flux will always be expelled from the superconducting material, independent of whether the magnetic field was applied before or after the onset of superconductivity. So the effect is independent of its previous history and thus is reversible in thermodynamic terms. Therefore superconductivity is a true thermodynamic state. The dependence of the critical magnetic field strength on temperature can be approximated very well by the simple expression (see fig.4b)

$$B_c(T) = B_c(0)\,[1 - (T/T_c)^2]\ .$$

Shortly after the discovery of the Meissner-Ochsenfeld-Effect a phenomenological theory of superconductivity was developed by F. and H. London. One of its predictions was that the magnetic field is not expelled completely up to the surface of the superconductor, but it penetrates into a narrow surface layer where the compensating currents flow. The characteristic length associated with this layer is called London penetration depth λ_L, and typically is of the order of 50 nm. The fact that all of the energy transport occurs within a narrow surface layer of a superconducting wire can be put to practical consequences: thousands of thin superconducting threads are embedded into a copper matrix, which carry the current below the critical temperature. Should superconductivity, however, break down the copper material can take over the current transport thus preventing destruction of the wire.

If one applies the Bohr-Sommerfeld quantization rule to a superconducting ring current (i.e., to a macroscopic system!) one obtains the result that magnetic flux is quantized, i.e., magnetic flux comes in elementary units of "fluxoids"

$$\Phi_0 = h/2e_0 = 2.07 \times 10^{-15}\ \mathrm{Tm}^2\ (= \mathrm{Wb})$$

where h is Planck's constant and e_0 the elementary unit charge. Actually, in the denominator the charge of the current carriers occurs that has been determined experimentally as twice the elementary unit charge, indicating a pairing of electrons in a superconductor (this will be elaborated in more detail in the following section).

BCS Theory

The BCS Theory (for which J. Bardeen, L.N. Cooper, and J.R. Schrieffer were awarded the Nobel Prize in 1972) is a quantum mechanical many-particle theory to explain superconductivity in metals. The experimental observation that the critical temperature shows a strong dependence on whether the metal contains more light or heavy isotopes ("isotope effect") indicated that mass dependent quantized lattice vibrations (whose quanta are called phonons) play a vital role in the formation of the superconducting state. Also an energy gap in the electronic excitation spectrum of superconductors below T_c was found in measurements of the specific heat, whose value pointed towards the formation of electron pairs in the superconducting state.

The basic idea behind the BCS Theory rests on the formation of so-called Cooper-pairs consisting of two electrons (with opposite momentum and spin, see below). This can be achieved by postulating a new weakly attractive electron-electron interaction through the emission and absorption of virtual phonons that can be interpreted in the following way: The emission of a virtual phonon by an electron is equivalent to a deflection of lattice ions and thus to a polarization of the lattice in its vicinity. If another electron enters this polarization cloud it experiences an attractive force (by absorbing the virtual phonon), independent of the Coulomb repulsion between the electrons (it should be noted here that the phonons exchanged can not be real since a real phonon would lead to an energy transfer to the lattice and thus would give rise to a nonzero resistance).

The resulting formation of Cooper pairs is a dynamic process, it depends on how fast the lattice can follow the polarizing action of the electrons, and therefore the masses of the ions play a crucial role, leading to the above mentioned isotope effect of the critical temperature. Since the lattice reacts much slower than the electrons travel through it, the coupling of the Cooper pair extends over distances of 100 nm to 1000 nm; this distance is called "coherence length" and can be interpreted as a mean extension of the Cooper pair. Within this distance there are of the order of 10^6 electrons, in the form of Cooper pairs that continually disintegrate and reform.

A quantum mechanical calculation shows that all Cooper pairs have total momentum and spin zero (at T = 0 K). Thus each Cooper pair acts like a boson which favours that all are in the same quantum mechanical energy state. The ensemble of all pairs is described by a single wave function spanning the whole superconductor. The binding energy of a Cooper pair is of the order of a few meV, much smaller than the binding energy of electrons in a metal (some eV), therefore the coupling of the electrons to Cooper pairs is only possible if the thermal energy of the lattice is small. This binding energy obviously gives rise to the above mentioned energy gap in the electronic spectrum.
Just below the critical temperature only a small fraction of the conduction electrons condense to Cooper pairs; as the temperature decreases more and more pairs are formed until at T = 0 K all are coupled.

When an electric field is applied, all pairs have the same momentum without any interaction with the lattice, leading to the observed resistanceless charge transport. However the momentum that can be transferred to the pairs is limited, once their kinetic energy exceeds their binding energy, superconductivity breaks down – this is the reason for the existence of a critical current. Also magnetic fields can only be applied up to a certain field strength, since the compensating current would then reach its critical value.

In conclusion it should be noted that the BCS-Theory needs only three parameters to express the essential features of superconductivity in metals: they are the characteristics of the electronic subsystem (density of states near the Fermi surface), of the lattice (characteristic phonon frequencies), and the electron-phonon coupling strength.

The Josephson Effects

If two superconductors are connected by a thin layer of a non superconducting material (of just a few nanometre thickness) then quantum theory predicts a non-vanishing probability that Cooper pairs may tunnel through the barrier from one superconductor to the other. The two superconductors are then said to be weakly coupled. Such an arrangement is called a Josephson junction, named after *Brian D. Josephson* who predicted the phenomenon theoretically in 1962 and was awarded the Nobel Prize in 1973, after experimental verification of his predictions. The Josephson junction may be a superconductor-insulator-superconductor (SIS) or superconductor-normal conductor-superconductor (SNS) combination, or realized by pressing a thin superconducting point onto another superconductor, or by a very narrow constriction in a superconducting film.

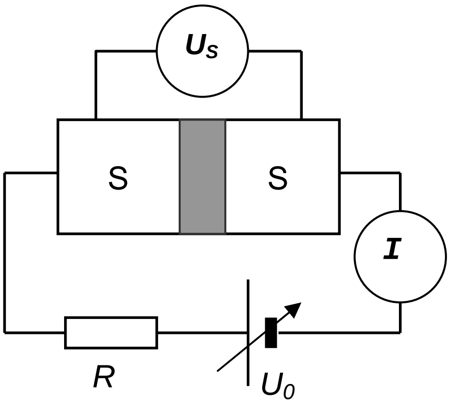


Fig. 5: Josephson junction

The fact that all Cooper pairs in a superconductor are in the same quantum mechanical state implies also that the phase of the wavefunction associated with them is well determined. If a voltage U_0 is applied to the junction, a resistanceless supercurrent I_s (Josephson current) will flow through it of magnitude

$$I_s = I_c \sin(\Delta\phi) .$$

There $\Delta\phi$ is the phase difference between the wavefunctions of the two coupled superconductors, in analogy to the phase difference between two weakly coupled mechanical pendula. The value of I_s can be increased by increasing the applied voltage U_0 up to the critical current I_c. This phenomenon is called the **DC Josephson effect**.
If the current becomes larger than I_c, a voltage U_s will appear across the barrier, i.e. a certain resistance has developed. This voltage implies an energy difference between the Cooper pair systems of magnitude

$$\Delta E = 2\ e_0\ U_s\ ,$$

and, according to quantum mechanics, this is equivalent to a difference in the inner frequencies of the systems of $\Delta\nu = \Delta E/h$. If the two systems oscillate with different, but time constant frequencies the phase difference between them changes linearly with time as

$$\Delta\phi(t) = 2\pi\ \Delta\nu\ t = (2\pi/\Phi_0)\ U_s\ t\ .$$

There the magnetic flux quantum Φ_0 appears again, its inverse is being called the Josephson constant K_J. As a consequence, an alternating supercurrent with the so-called Josephson frequency

$$\nu_J = 2\ e_0\ U_s/h$$

now flows across the barrier. This establishes then the **AC Josephson effect**.
Josephson junctions are used as extremely fast switching elements and accurate voltage stabilisators. In addition they are employed in measuring devices for extremely small magnetic fluxes (SQUIDs = Superconducting Quantum Interference Devices).
In the **inverse AC Josephson effect**, an alternating voltage of frequency ν is applied to the Josephson junction (usually by irradiating it with microwaves). It then creates discrete steps of voltage between the two superconductors of the form

$$U_n = n\ \Phi_0\ \nu, \quad n = 1, 2, 3, \ldots$$

Thus the Josephson junction acts as a perfect frequency-to-voltage converter. Therefore it is used world-wide as basis for constant reference voltage in metrological national institutes and in calibration laboratories of industry.
Finally it should be noted that the Josephson effects have also been successfully demonstrated with the new High-Temperature Superconductors.

Type I / Type II Superconductors

The phenomena and their theoretical interpretation as described in Sections 2 to 4 related to so-called Type I Superconductors that are characterized by exhibiting a complete Meissner-Ochsenfeld-Effect below T_c and B_c: An applied magnetic field decreases exponentially within the London penetration depth where a supercurrent flows to keep the interior field-free. Above the critical field strength B_c the Cooper pairs break up and the material becomes a normal conductor. Materials showing this behaviour are usually pure metals that are characterized, however, in general by low values of the critical temperature and magnetic field strength. Therefore they are not very useful for technical applications.

In contrast to these, so-called Type II Superconductors (usually alloys and compounds) show a different magnetization behaviour: below a first critical magnetic field B_{c1}, they are in a so-called Meissner state and exhibit a complete Meissner-Ochsenfeld-Effect (like a Type I Superconductor). Between this critical field and a (usually much higher) second critical field B_{c2} they show an incomplete Meissner-Ochsenfeld-Effect, meaning that an applied magnetic field can enter the material. Above B_{c2} superconductivity breaks down (see fig. 6a).

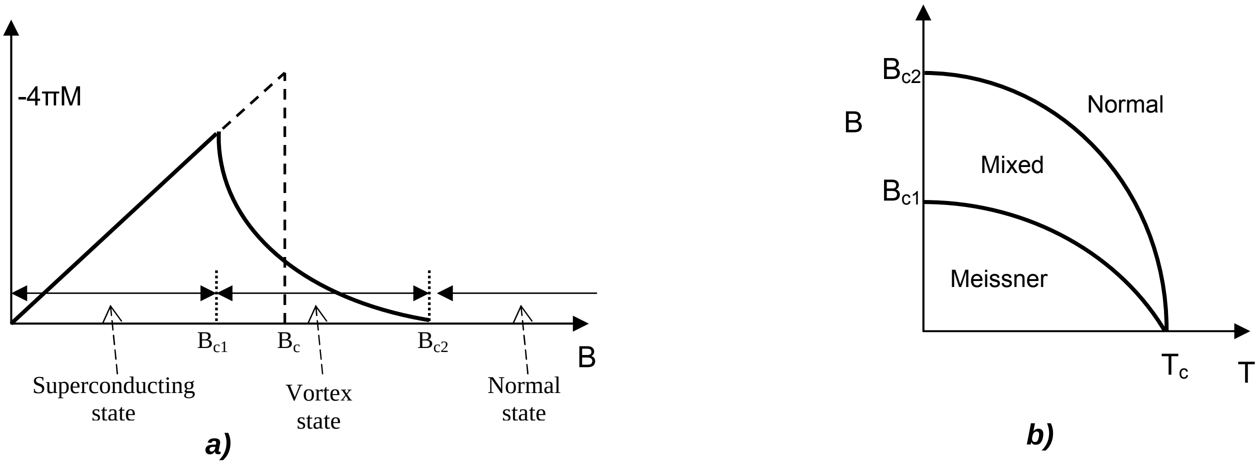


Fig. 6: a) Induced magnetization in a Type II superconductor as function of the applied magnetic field
b) Dependence of the critical magnetic field strengths on temperature

In the intermediate state (mixed, Abrikosov or vortex phase) it is energetically favoured that vortices of unit magnetic flux Φ_0 exist in the material. These vortices are in the normal conducting phase and are surrounded by superconducting regions where superconducting ring currents flow (see fig. 7). As the magnetic field increases from B_{c1} to B_{c2}, more and more vortices enter the material; since they repel each other, an ordered two-dimensional hexagonal lattice of vortices evolves. This has actually been seen under the microscope.

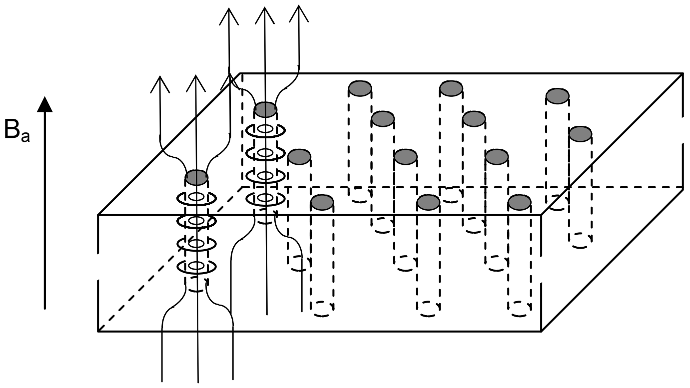


Fig. 7: Drawing of vortices in a Type II Superconductor

The theoretical foundation of these phenomena has been laid down by the work of *V.L. Ginzburg* and *L.D. Landau* (1950) that has been later extended by *A.A. Abrikosov* (1957) and *L.P. Gor'kov* (1960). *Abrikosov* and *Ginzburg* were awarded the Nobel Prize in 2003 for their work (*Landau* having died in 1968). One may express the essential features by considering characteristic length scales: First one defines an effective coherence length ξ that depends on the "intrinsic" coherence length ξ_0 (i.e., the "extension" of a Cooper pair), and the mean free path l of the electrons in the normal conducting state (which stands for a resistance, i.e., small/large l means bad/good conductor) through

$$1/\xi = 1/\xi_0 + 1/l$$

This coherence length has to be compared to the London penetration depth λ_L. In a pure superconductor (with large l) ξ is approximately equal to ξ_0 and much larger than λ_L. On the other hand, in the "dirty limit" with small l, ξ may become less than λ_L, and the superconducting state will be modified such that a magnetic field can enter the material, i.e. it is a Type II Superconductor.

The same length scales determine the critical magnetic field strengths: B_{c1} is governed by λ_L, and B_{c2} by ξ, such that their product is approximately equal to the "thermodynamic" critical field B_c (see fig. 6a),

$$B_{c1}\, B_{c2} \approx B_c^2 \,.$$

Ideally, the vortices can travel freely through the material, but defects (grain boundaries, point defects, etc.) tend to pin them down. This pinning has technical advantages: much higher magnetic fields can be produced in such "Hard Superconductors" (around 50 Tesla). Also, since a magnetic field exists in large parts of the material, almost the entire cross section can be used for the current transport, allowing quite high critical currents to be sustained. By appropriate processing of materials, Type I Superconductors can be made to (hard) Type II Superconductors.

High-Temperature Superconductors

High-Temperature Superconductors are superconductors that possess critical temperatures well above 30 K. Until 1986 it was commonly believed that, according to the BCS-Theory, superconductivity above 30 K were not possible. But in that year, *J.G. Bednorz* and *K.A. Müller* discovered superconductivity in cuprate-perovskite ceramic materials ($La_{2-x}Ba_xCuO_4$) with critical temperatures between 30 K and 40 K (for that they have been awarded the Nobel Prize in 1987). Shortly afterwards it was found that replacing lanthanium by yttrium, i.e., making $YBa_3Cu_3O_7$, the critical temperature could be raised to 93 K. This material, also known as YBCO or 123-compound, is now one of the best studied high-temperature superconductors.

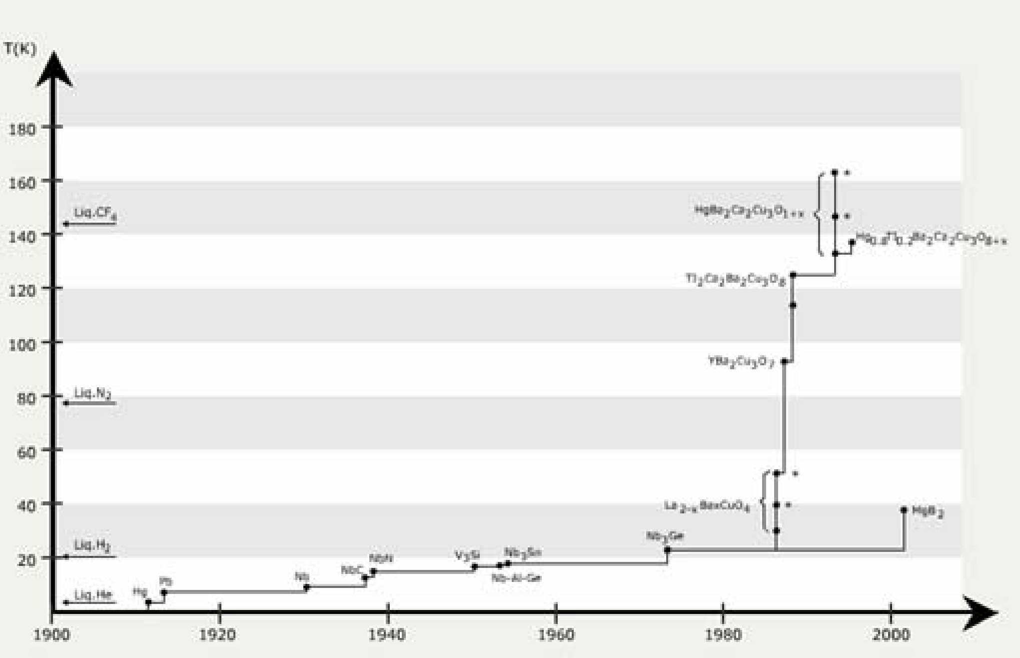


Fig. 8: Development of high-temperature superconductivity

Thus, cooling with liquid nitrogen (boiling point at 77 K) became possible, making technical applications much easier and less expensive. In the following years many other related materials have been discovered with even higher critical temperatures, the official record (as of March 2007) being T_c = 138 K for $Hg_{0.8}Tl_{0.2}Ba_2Ca_2Cu_3O_8$. Under high pressure, the mercury compound $HgBa_2Ca_2Cu_3O_8$ reaches a critical temperature of even more than 160 K. Also a patent has been applied for a material with a critical temperature of up to 150 K.

Unfortunately, the mechanism underlying high-temperature superconductivity is still not resolved, although some common features of the high-T_c cuprates have already been found: All cuprates without doping are antiferromagnetic insulators, doping makes them metallic and thus superconducting. There exists an optimum doping concentration, below and above which T_c is lower. The charge carriers of most high-T_c superconductors are holes (= defect electrons). Common structure elements are CuO_2 planes that are mainly responsible for the supercurrent. One possible candidate for the formation of Cooper pairs (that are essential for superconductivity) may be an antiferromagnetic spin-spin-interaction, whereas phonons (as in the BCS-Theory) are most probably ruled out. Much work is still going on to find a fundamental theory of high-temperature superconductivity.

As a final note, in 1964 a hypothesis was put forward that organic materials may show superconductivity with very high critical temperatures. This expectation, however, has not been confirmed since then, but indeed organic superconductors have been found with critical temperatures around 10 K.

Credits

Parts of this article were adapted from W. Buckel and R. Kleiner, Superconductivity: fundamentals and applications, Wiley, Weinheim (2003), especially some of the figures.

Also a manuscript by C. Ambrosch-Draxl for a course on superconductivity at the University of Graz was very helpful. Figures 2, 4a and 6a were adapted from Ch. Kittel: Introduction to Solid State Physics, 7th ed., Wiley, New York (1996).

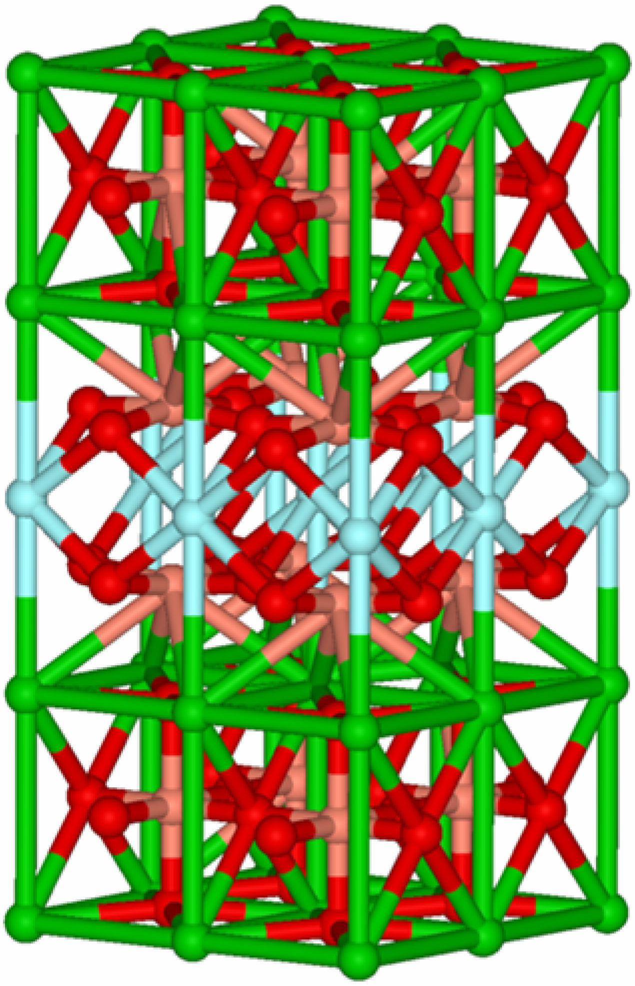


Figure: 3D-model of YBCO
http://commons.wikimedia.org/wiki/Image:YBCO-3D-balls.png

The e-modules

Overview

What is the science behind superconductivity?
Magnetism

Who are the people behind superconductors?
History of superconductivity

What is superconductivity?
Introduction to superconductivity

What is the science behind superconductivity?
Electromagnetic induction

What are superconductors made of?
Superconducting materials

What is superconductivity good for?
Applications of superconductivity

What is the science behind superconductivity?
Electrical conduction

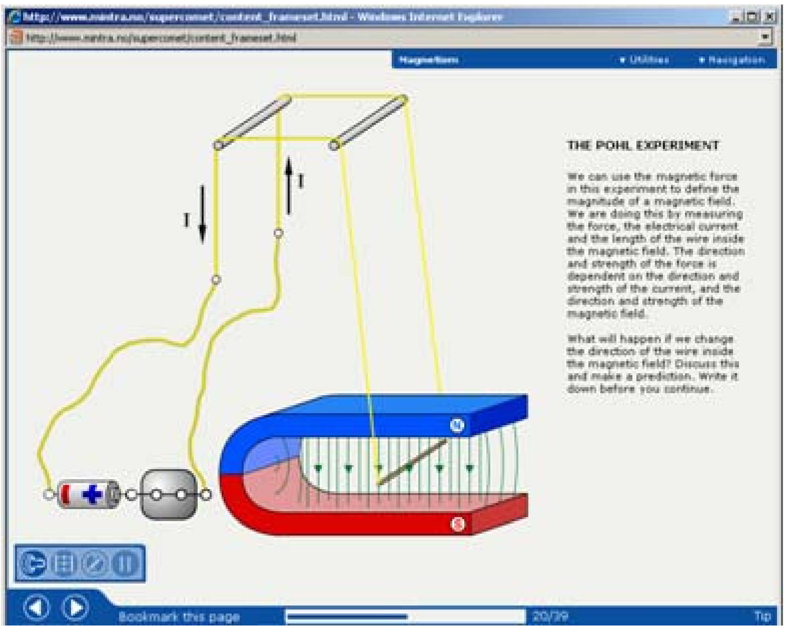
How does superconductivity work?
Explanation of superconductivity

Can we work with superconductors in school?
Activities with superconductors

The main menu in the learning application is organized like a mind map of the modules, showing the connections between the different topics covered by each module. Begin where you want, there is no specific sequence you must follow.

Magnetism

This module connects naturally occurring and easily observable magnetic forces with the concept of a magnetic field. Some materials are naturally magnetic, others are not. Magnetic materials are sometimes called magnets, and magnets are surrounded by magnetic fields. The user can investigate the magnetic fields associated with wire loops and coils. Also, the module shows the different magnetic properties of ferro-, para- and diamagnetic materials.



THE POHL EXPERIMENT

We can use the magnetic force in this experiment to define the magnitude of a magnetic field. We are doing this by measuring the force, the electrical current and the length of the wire inside the magnetic field. The direction and strength of the force is dependent on the direction and strength of the current, and the direction and strength of the magnetic field.

What will happen if we change the direction of the wire inside the magnetic field? Discuss this and make a prediction. Write it down before you continue.

- Magnetic field around straight wires
- Magnetic field around magnets
- Magnetic field around loops of wire
- Magnetic forces
- Lorentz force on a wire
- Dia-, para- and ferromagnetism

Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

1. recognize that there exists a natural force called magnetism, that magnets have poles, and that magnets attract and repel each other at a distance
2. recognize that magnetic fields are areas around and within a magnet where magnetic forces can be felt
3. recognize that the magnetic field lines go into and radiate from the poles of the magnet
4. recognize that an electric current in a wire will generate a magnetic field around that wire
5. recognize basic concepts of electric circuits

Learning objectives

Based on work with the SUPERCOMET material, the pupils shall be able to

Knowledge

- recognize that the Earth has a magnetic field
- recognize that electricity and magnetism are two faces of the same phenomenon
- recognize that there is always a magnetic field associated with an electric current
- recognize that the magnetic field around a solenoid is similar to the field of a bar magnet
- recognize the different properties of paramagnetic, diamagnetic and ferromagnetic materials
- recognize that a ferromagnetic material can be magnetized by an external magnetic field and can lose its magnetization if it is heated up sufficiently

Understanding

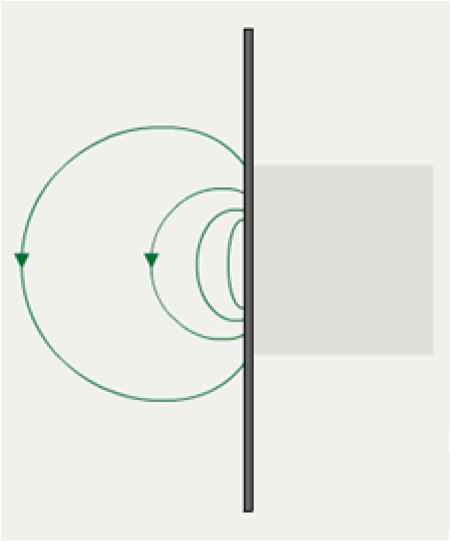
- describe the significance of the Ørsted experiment
- understand the significance of the Ampere experiment
- explain the conditions of the force in the Pohl experiment
- describe how the shape of the magnetic field from a solenoid is related to that of a straight wire
- describe the significance of using ferromagnetic cores in electromagnets
- give a simplified account of the domain theory of magnetism

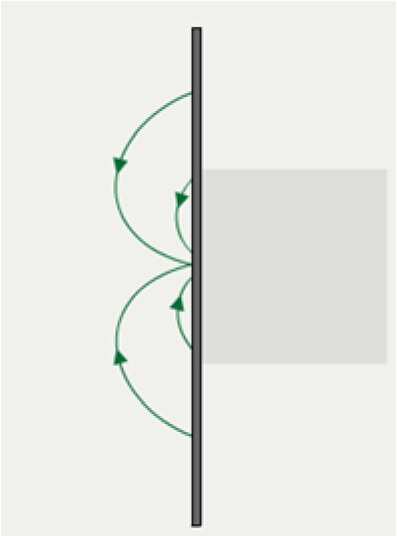
Skills

- apply the right hand rule to determine the direction of the magnetic field around a wire
- draw the magnetic fields around common magnet geometries (bar magnets, horseshoe magnets)
- apply the concept of Weiss' domains to explain properties of magnets

Knowledge testing

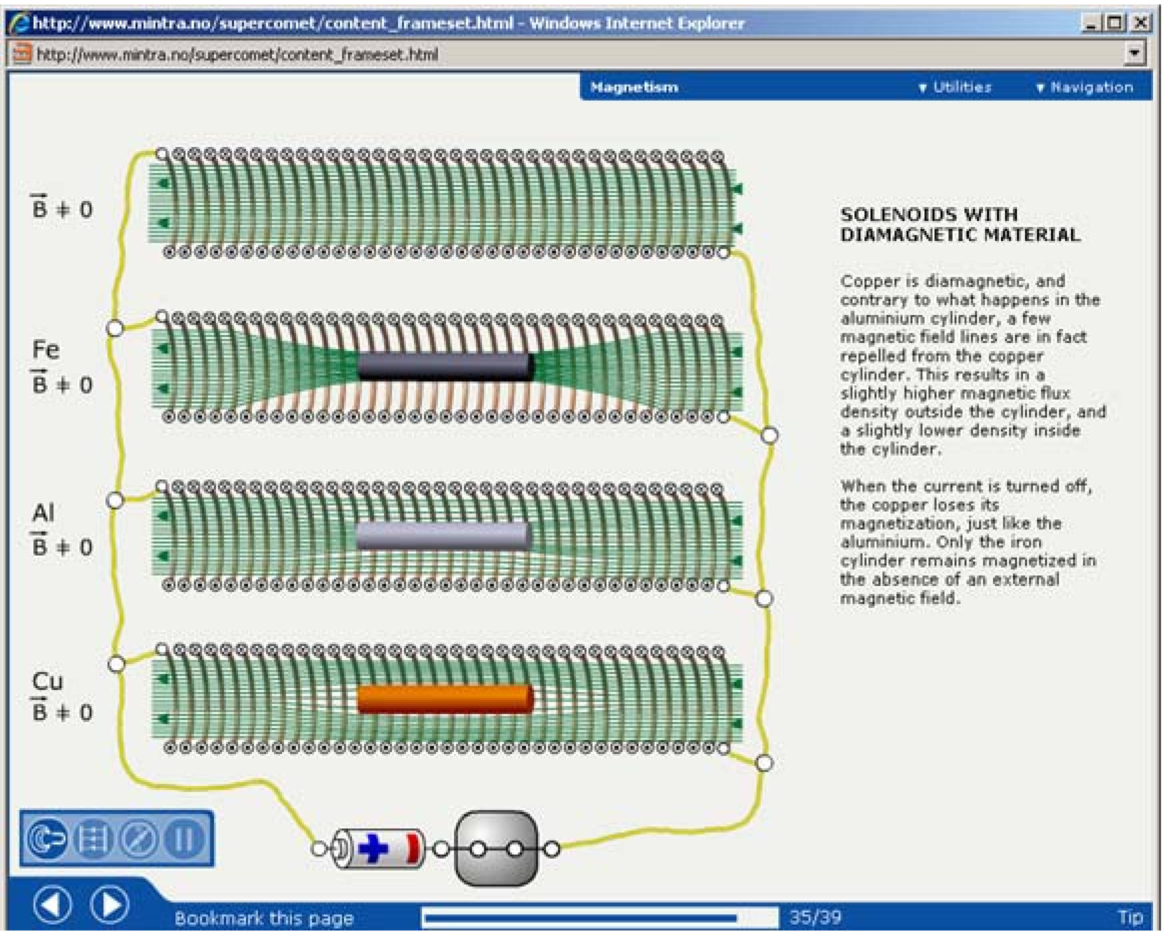
- Give two properties of a magnet!
- Give two applications of an electromagnet!
- What does the Ørsted experiment tell us?
- Draw magnets, which can cause the fields shown!
- How can the Ampere experiment be used for the definition of the unit of the electric current?
- Which variables affect the strength of the force in the Pohl experiment?
- With the Pohl experiment you can simulate a kind of motor. Describe how?
- Give two examples for the connection of magnetism and electricity.





- Which difference have you observed between the field lines of a magnetic field produced by a wire and those produced by a magnet?
- The magnetic field is described by the magnetic induction vector (B), which relation do you think this vector has with the field lines? Which relation do you think the vector B has with the interaction strength that is experienced by a wire of length l, undergoing a current I, immersed in the magnetic field in such a way as to create an angle Θ with the field lines of the field itself?
- Have you noticed that there is a strong analogy between the field lines generated by a solenoid and those of a bar magnet? Can you comment on the field lines within a magnet? What will be their direction? (please, justify you answer)
- What is the peculiarity of field lines that suggests that the magnetic field within a solenoid can be considered homogeneous (uniform) ?

- Explain the direction of the magnetic field applying the right hand rule.
- Describe the varying properties of paramagnetic, diamagnetic and ferromagnetic materials.
- Do you think that a ferromagnetic body should be attracted or repelled by a magnet? And how about a diamagnetic one? (please, justify you answers)
- Consider the behaviour of ferromagnetic and magnetic materials (magnets) when they get close to a magnet. Try the experiment either at home or in the laboratory by using materials made up of different substances (e.g. wood, rubber, iron, aluminium, copper, other magnets…) and list the similarities and differences. Which hypothesis can be formulated in relations to what you have observed?
- How can a piece of iron be made into a magnet? Give two ways in which the magnet can be destroyed!
- Why are ferromagnetic cores used in electromagnets?
- Explain the origin of magnetism in iron applying the concept of “Weiss domains”.
- What type of metals become superconductors when cooled down?



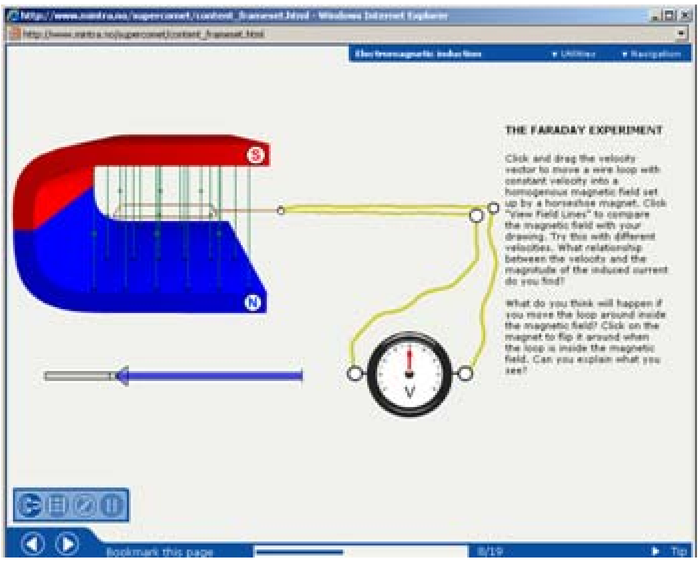
SOLENOIDS WITH DIAMAGNETIC MATERIAL

Copper is diamagnetic, and contrary to what happens in the aluminium cylinder, a few magnetic field lines are in fact repelled from the copper cylinder. This results in a slightly higher magnetic flux density outside the cylinder, and a slightly lower density inside the cylinder.

When the current is turned off, the copper loses its magnetization, just like the aluminium. Only the iron cylinder remains magnetized in the absence of an external magnetic field.

Electromagnetic induction

This module uses animations to connect the phenomena of magnetism and electricity. Magnets and coils can be used to transfer energy from the magnetic field to the flow of an electric current by a process called induction. This is similar to a magnetic field being formed by the moving electric charges in an electric current. Both of these phenomena are observed in voltage transformers.



THE FARADAY EXPERIMENT

Click and drag the velocity vector to move a wire loop with constant velocity into a homogeneous magnetic field set up by a horseshoe magnet. Click "View Field Lines" to compare the magnetic field with your drawing. Try this with different velocities. 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? Click on the magnet to flip it around when the loop is inside the magnetic field. Can you explain what you see?

- Induction by movement
- Induction by flux change
- Flux proportionality, Lenz' law
- Applications of induction
- Experiments with induction

Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

1. use the concepts of magnetic field, magnetic force, magnetism
2. recognize that an electric field surrounds every charged particle
3. recognize that electrons can move through a metallic conductor
4. recognize that electricity and magnetism are two faces of the same phenomenon
5. recognize that an electric current creates a magnetic field

Learning objectives

Based on work with the SUPERCOMET material, the pupils shall be able to

Knowledge

- use the terms induction, coil, circuit, current, magnetic flux, generator, rotor, stator, dynamo
- identify some applications of induction coils in everyday technology (e.g. transformers, generators)

Understanding

- describe the phenomenon of induction
- describe how AC current is generated in terms of induction, magnet, coil and rotation
- describe how AC current can be transformed from one voltage to another by passing it through a transformer

Knowledge testing

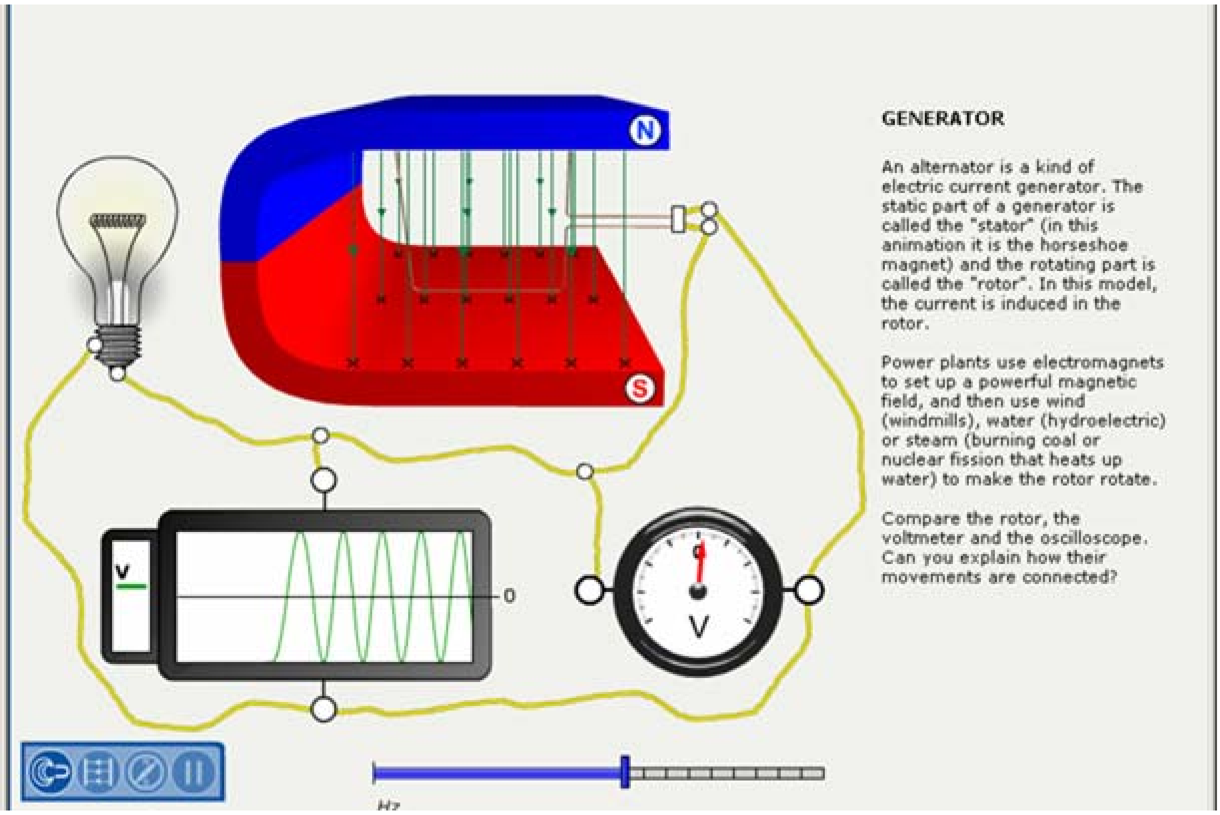
- What is the definition of the flux of a magnetic induction vector? Please, specify the meaning of the symbols used, and illustrate your answer with a diagram. In the International System of Units, the unit of flux is called Weber (Wb). What is the relation between the Wb and Tesla?
- Consider a solenoid, not connected to a current generator. In which of the following situations is a current generated in the solenoid: (i) when the flux inside the solenoid is constant; (ii) when it increases; or (iii) when it decreases?

- In a generator, if instead of rotating the coil around the magnet, the magnet was rotated around the coil, would there still be a current generated within the coil? Please justify the answer.

- What does Lenz’s law state?

- Is a transformer a device that transforms direct current into alternating current and vice versa? If so, please explain the working principle, if not, please specify the role of the device.

- Now we know that an electric current generates a magnetic field and that a magnetic field can generate an electric current. What are the similarities and differences between the two?



GENERATOR

An alternator is a kind of electric current generator. The static part of a generator is called the "stator" (in this animation it is the horseshoe magnet) and the rotating part is called the "rotor". In this model, the current is induced in the rotor.

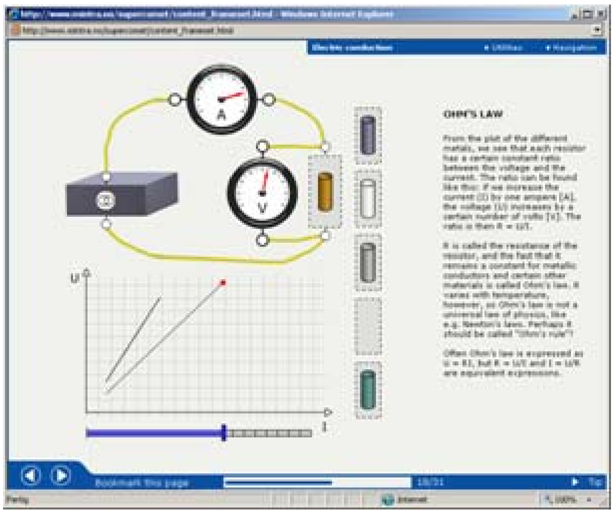
Power plants use electromagnets to set up a powerful magnetic field, and then use wind (windmills), water (hydroelectric) or steam (burning coal or nuclear fission that heats up water) to make the rotor rotate.

Compare the rotor, the voltmeter and the oscilloscope. Can you explain how their movements are connected?

Electrical conduction

This module uses animations to visualize the phenomenon of electric conduction. Some materials conduct electricity, others are insulators. Some are semi-conducting, and some are superconducting.

- Types of conductors
- Particle & Bohr models
- Drift velocity
- Ohm’s law
- Resistance factors
- Resistance and temperature



Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

1. use the concepts electricity, electric current
2. understand that a given body is charged when it has an excess or a lack of electrons
3. describe an atom using the shell model
4. recognize a direct or inverse proportionality between quantities
5. use the terms temperature and heat

Learning objectives

Based on work with the SUPERCOMET material, the pupils shall be able to

Knowledge

- use the terms conductor, semi-conductor, resistor, insulator, cross-section, resistivity, temperature coefficient, mean free distance, lattice, charge carrier, electrons, ions, power loss
- recognize electrons and ions as charge carriers
- identify some well-known conductors, insulators and semi-conductors

Understanding

- describe the relationship between the kinetic energy of the lattice (temperature of the material) and resistance
- describe the relationship between voltage, current and resistance (Ohm’s first law)
- describe the relationships between resistance, cross-section, length and resistivity of the material (resistance law or Ohm’s second law)

Skills

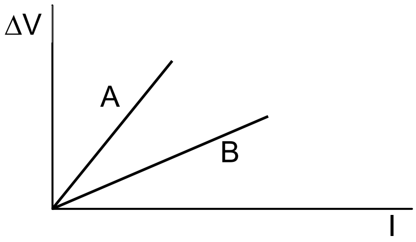
- use Ohm’s first law in its algebraic form
- use Joule’s law to calculate power loss in power lines
- calculate the resistance of a piece of (conducting) material using the parameters cross-section, length and resistivity of the material

Suggested discussion topics

1. How much power is lost through heat dissipation from power lines before the power is available to end users at outlets in the wall?
2. How does this power loss compare to the amount of power used in an average household?
3. How much power could be «saved» by increasing the voltage on high-capacity power lines?

Knowledge testing

- What is an electric current?
- Define current intensity. What are its units?
- How can we classify materials according to their behaviour with respect to electric currents?
- Why are metals good conductors?
- Conventionally, what is the direction of the electric current?
- What is needed to produce an electric current between two points?
- Define the electrical resistance R between two points of a conductor.
- On what intrinsic factors of a piece of conductor does its electrical resistance depend? Express R as a function of those factors.
- A piece of copper cable has 5 cm length and is 0,5 mm^2 thick. The resistivity of copper is $1{,}7\cdot 10^{-8}\ \Omega\cdot m$. If there is a potential difference of 4 V between the ends of this piece, what is the intensity of the current flowing through it?
- What does Ohm's law state?
- Do all materials obey Ohm's law? If some of them do not, why?
- Draw diagrammatically (with standard symbols to represent electric circuit elements) a circuit with a battery, a resistor, an ammeter to measure the current going through this resistor and a voltmeter to measure the potential difference between the ends of a resistor.
- This graph represents, for two conductors A and B, the potential difference between their ends ΔV, in terms of the current intensity I. What can you say about each of them?



- When an electric current flows through a piece of a conductor, it warms up. Where does the energy transfer occur?
- Write down Joule's law for the quantity of heat Q generated in a piece of conductor as function of the current intensity I running through it, its resistance R and of the time interval considered Δt.
- If the temperature of a piece of conductor increases, how will it affect its resistance? What is the explanation for this change?

History of superconductivity

This module presents the scientists behind the discoveries and theories of superconductivity, and what they did to get the Nobel prizes that have been awarded for superconductivity research throughout history. A short introduction of current scientific teams working on superconductivity is given. The importance of the increase of critical temperature in 1987 is discussed, and why high-Tc superconductors might have a profound impact on society.

- Discovery of superconductivity
- Model for superconductivity
- Theory of superconductivity
- Superconductivity in organic materials
- Superconductivity in ceramic materials
- Developing applications

Heike Kamerlingh Onnes
http://commons.wikimedia.org/wiki/Image:Kamerlingh_portret.jpg

Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

1. recognize that there exists a phenomenon called superconductivity
2. recognize that superconductivity relates to electricity and magnetism
3. recognize the characteristics of superconductivity (no resistance, no magnetic permeability)
4. recognize the need for cooling superconductive materials below their critical temperature
5. recognize that the magnetic field lines go into and radiate from the poles of the magnet.

Learning objectives

Based on work with the SUPERCOMET material, the pupils shall be able to

1. recognize some major discoveries and theories related to superconductivity
2. recognize the scientists and the collaboration behind these discoveries and theories
3. recognize current efforts to improve experimental knowledge and theories of superconductivity
4. describe how the superconductivity scientists gained and interpreted their data
5. argue how the superconductivity theories (BCS and HTS) are related to experimental evidence
6. discuss whether superconductivity development has been driven by experiments or by theory

Knowledge testing

- How did Heike Kamerlingh Onnes discover superconductivity in 1911?
- Why was superconductivity first discovered in mercury (Hg)?
- Why did Onnes have to use liquid helium for cooling down the mercury?
- Why is liquid nitrogen used for cooling down high temperature superconductors?
- Why did it take so many years after the discovery of low temperature superconductors before someone discovered high temperature superconductors?
- What is the basic idea of the so called “BCS-theory”?
- Give two applications of superconductors from different fields

Suggested virtual laboratories

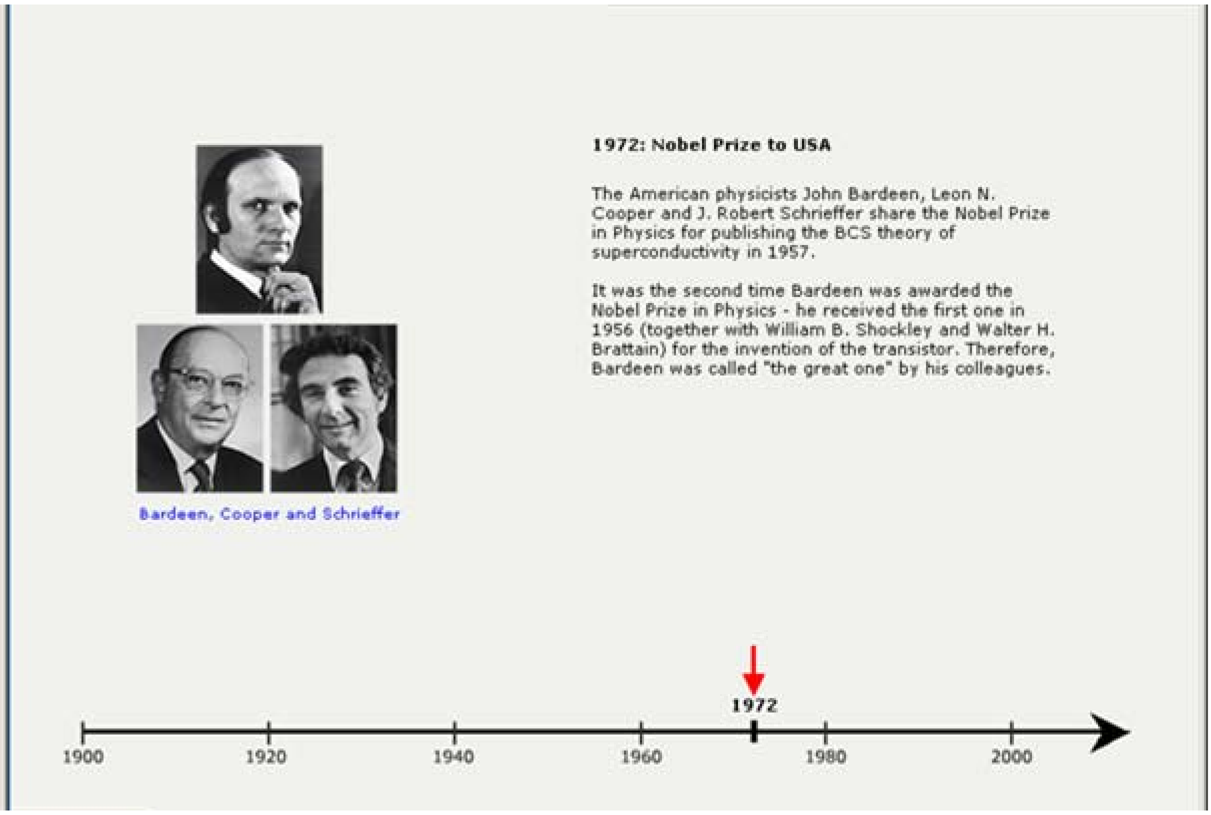
Discover superconductivity in different materials
Repeat Heike Kamerlingh Onnes' historical experiment with different materials and cooling agents. Measure the electric resistance as a function of temperature.

Measure magnetic permeability in different materials
Repeat the historical experiment that discovered the Meissner effect. Use different materials and cooling agents, and measure the magnetic permeability as a function of temperature.

Suggested learning activities

These learning objectives can be connected to certain activities or scenarios for learning to take place:

1. Discuss "what if the discovery of superconductivity happened tomorrow instead of in 1911?"
2. Discuss if it could be possible that we had not discovered superconductivity yet, and why.
3. Discuss "what if the discovery of ceramic HTS by chance had happened before metallic LTS?"
4. Discuss "what if the discovery of ceramic HTS happened tomorrow instead of in 1986?"
5. Discuss if it could be possible that we had not discovered HTS yet, and why.
6. Discuss "what if the BCS theory of LTS was presented before the discovery of LTS itself?"
7. Imagine if the discovery of room-temperature superconductors happens tomorrow.
8. Reading books or articles about superconductivity research and researchers.



1972: Nobel Prize to USA

The American physicists John Bardeen, Leon N. Cooper and J. Robert Schrieffer share the Nobel Prize in Physics for publishing the BCS theory of superconductivity in 1957.

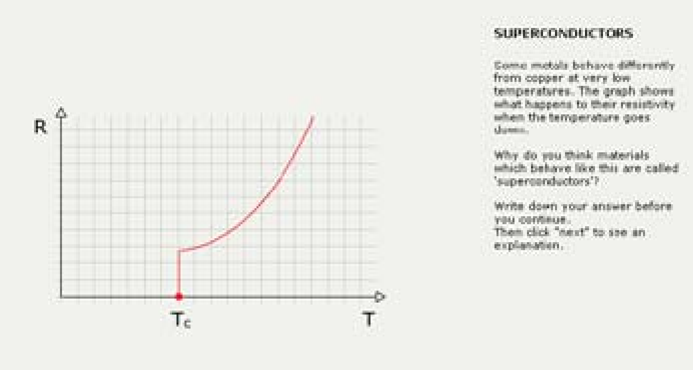
It was the second time Bardeen was awarded the Nobel Prize in Physics - he received the first one in 1956 (together with William B. Shockley and Walter H. Brattain) for the invention of the transistor. Therefore, Bardeen was called "the great one" by his colleagues.

Bardeen, Cooper and Schrieffer

Introduction to superconductivity

This module introduces readers to the concept of superconductivity and how it relates to – and extends – electricity and magnetism. It runs through the main phenomena of superconductivity, the properties of different forms of superconductors and the theoretical explanations which underpin them.

- Zero resistivity
- Critical temperature
- Perfect diamagnetism
- Stable levitation



SUPERCONDUCTORS

Some metals behave differently from copper at very low temperatures. The graph shows what happens to their resistivity when the temperature goes down.

Why do you think materials which behave like this are called 'superconductors'?

Write down your answer before you continue.
Then click "next" to see an explanation.

Prerequisites

In order to work comfortably through 'Introduction to Superconductivity', the pupils should already

1. have a working knowledge of electricity and magnetism
2. be able to distinguish between conductors, semiconductors and insulators and give examples of each
3. be able to explain the relationship between resistance and temperature of normal conductors, including a basic understanding of lattice vibrations and internal energy

Learning objectives

Related to phenomena

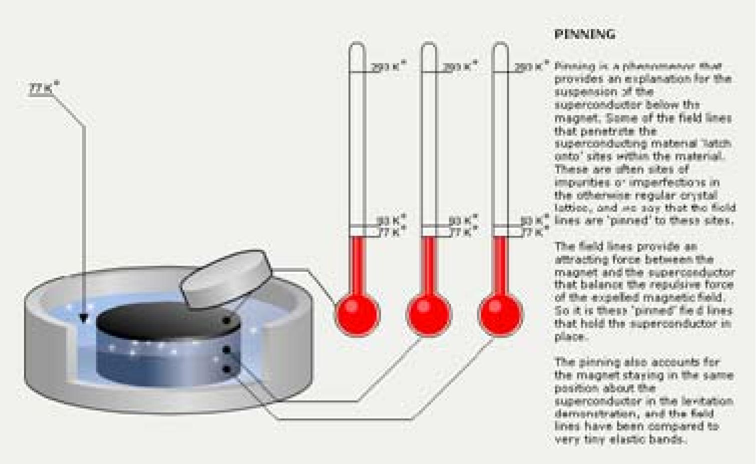
By the end of this module pupils should:

- be intrigued by the behaviour of superconductors;
- be able to describe both electrical and magnetic phenomena associated with superconductors;
- be able to compare the behaviour of superconductors with that of semiconductors and 'normal' conductors;
- be able to identify differences between 'ordinary' magnets and magnetic properties of superconductors;
- be able to give an account of the following terms related to phenomena in superconductivity: resistivity, ceramic materials, rare earths, critical temperature, critical magnetic field, critical current density, diamagnetism, phase transition, levitation, Meissner effect, pinning, Type I and Type II superconductors, so-called 'high' and 'low' temperature superconductors;
- have sufficient background understanding of superconductivity phenomena to be able to explain why superconductors are used in MRI machines for brain scanning in hospitals and in magnetically levitated trains.

Related to theory

By the end of this module pupils should be:

- able to recognize the theoretical puzzles which superconductivity presented (and still presents) to scientists;
- able to use existing knowledge of electricity and electromagnetism, and of lattice vibrations and internal energy, to understand some of the explanations;
- able to recognize that the rules of quantum mechanics dictate behaviour at low temperatures – and that some explanations of superconductivity cannot be accounted for in simple terms;
- aware that the following terms are used in explanations of superconductivity: drift velocity of electrons, eddy currents, penetration depth of magnetic field, Cooper pairs, phonons, vortices, fermions, bosons.



PINNING

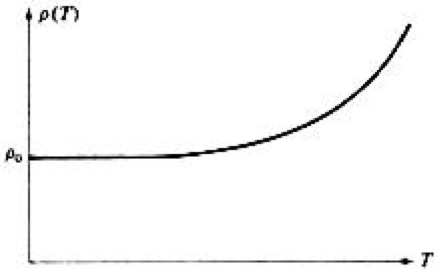
Pinning is a phenomenon that provides an explanation for the suspension of the superconductor below the magnet. Some of the field lines that penetrate the superconducting material 'latch onto' sites within the material. These are often sites of impurities or imperfections in the otherwise regular crystal lattice, and we say that the field lines are 'pinned' to these sites.

The field lines provide an attracting force between the magnet and the superconductor that balance the repulsive force of the expelled magnetic field. So it is these 'pinned' field lines that hold the superconductor in place.

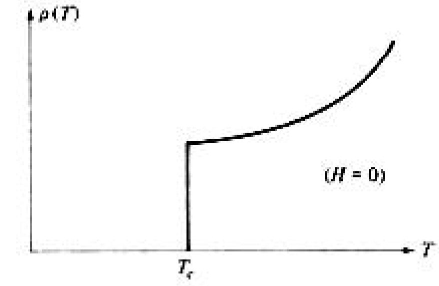
The pinning also accounts for the magnet staying in the same position about the superconductor in the levitation demonstration, and the field lines have been compared to very tiny elastic bands.

Knowledge testing

1. Into how many classes can the interaction of different types of materials with a magnet be divided? In what ways do they differ?
2. In a closed circuit an induced current is generated every time there is a variation of magnetic flux within it, and the phenomenon lasts whilst there is a flux variation.
    a. Is this sentence always right?
    b. Justify your answer.
3. In conductors and in metals generally, the resistance varies with the temperature. When the temperature rises, the resistance increases. Why?
4. By superconductivity is meant the vanishing of electrical resistivity that certain materials exhibit below a certain critical temperature T_c. Is the transition of a material to a superconductive state a reversible or an irreversible process? Justify your answer.
5. Do you think that a magnetized normal conductor – brought into a state of 'perfect conductor' ($T < T_c$) – and a superconductor immersed into a magnetic field and then taken below critical temperature behave in the same way? (Notice that a superconductor below critical temperature, immersed in a magnetic field, becomes perfectly diamagnetic). Justify your answer.
6. Why is the electric field inside a superconductor, cooled below critical temperature, equal to zero?
7. How can superconductors be divided into groups, and how are they characterized?
8. Which are the critical differences between the superconducting state and the normal state of a material that influence their behaviour?
9. The graphs (a) and (b) below illustrate the relationship between resistivity and temperature for conductors and superconductors.
    a. Which graph represents which?
    b. What is the difference in the relation between resistivity and temperature in a superconductor and in a normal conductor?



(a)



(b)

10. In which commercial sectors are superconductors employed?
11. What difficulties are encountered in the manufacture of technological components that utilize superconductors?

Applications of superconductivity

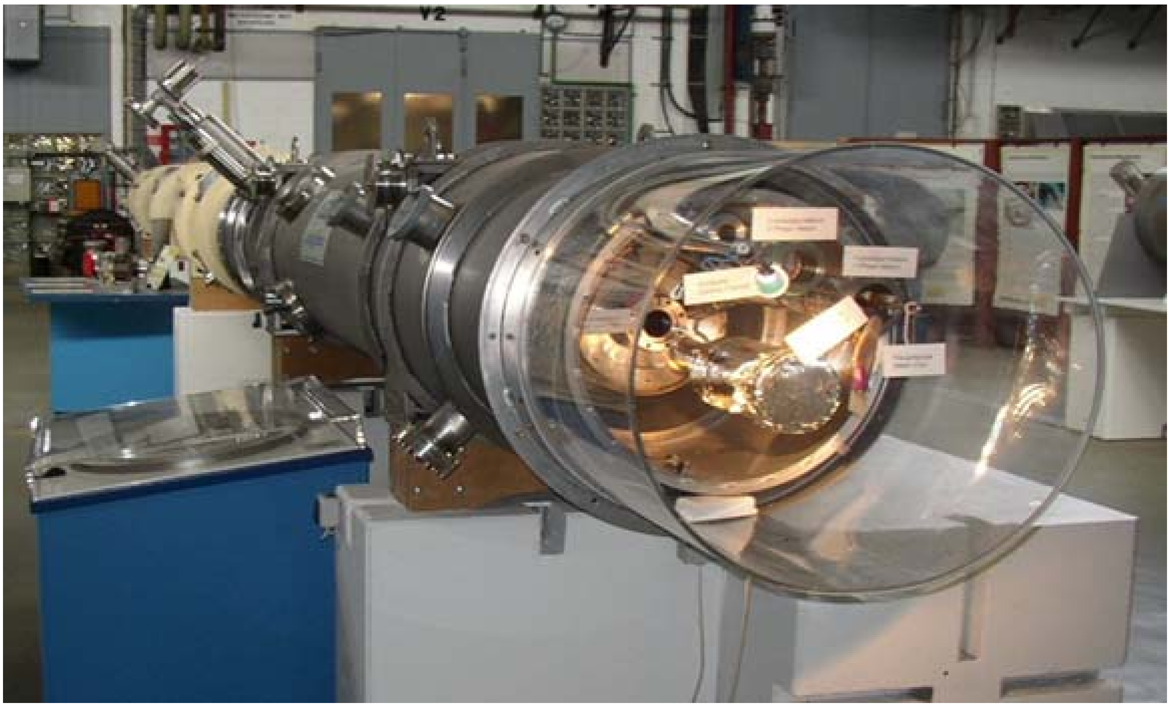
This module discusses the impact of superconductivity and superconductor technology on society, with current large and small scale applications for research, propulsion, medicine and industry. Furthermore the module discusses the possibilities of future applications related to the production, storage and transportation of energy, as well as propulsion/transportation with boats, cars, planes and trains. References to modules Introduction and History of Superconductivity.

- Faster. cleaner, safer energy transportation
- Cleaner energy storage
- Cleaner energy generation
- Faster, less painful medical imaging
- More precise scientific measurements
- Measuring energy use
- More efficient wireless communication

Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

- recognize that there exists a phenomenon called superconductivity
- recognize that superconductivity relates to electricity and magnetism
- recognize the characteristics of superconductivity (zero resistivity, zero magnetic permeability)
- recognize the need for cooling superconductive materials below their critical temperature
- recognize that the magnetic field lines go into and radiate from the poles of a magnet



Description: Segment of **HERA** (Hadron-Elektron-Ring-Anlage, "Hadron-Electron-Ring-Facility"), largest synchrotron and storage ring at DESY (Deutsches Elektronen Synchrotron, "German Electron Synchrotron") in Hamburg, Germany.
Front: Superconducting quadrupol magnet (silver), back: superconducting dipol magnet (white)
http://commons.wikimedia.org/wiki/Image:DESY1.jpg

Learning objectives

Based on work with this module, the pupils shall be able to

1. recognize some major current **large scale** applications of superconductivity technology
    - a. commercial (electromagnetic engines, food scanners)
    - b. scientific (particle accelerators)
    - c. medical (MRI)
    - d. LTS versus HTS (which type is used where, and why)
2. recognize some major current **small scale** applications of superconductivity technology
    - a. commercial (are there any?)
    - b. scientific (Josephson devices)
    - c. medical (SQUID)
    - d. LTS versus HTS (which type is used where, and why)
3. describe how superconductivity is improving everyday life for ordinary people
4. describe how superconductivity is aiding scientific researchers and other specialists
5. recognize major areas where future applications are planned, and necessary requirements
    - a. energy transfer (SC cables)
    - b. energy production (fusion reactors)
    - c. energy transformation (electromagnets, EM engines)
    - d. transportation (Maglev trains, space elevators, EM water propulsion)
6. recognize the challenges that need to be overcome before future applications can happen

Testing knowledege

1. What is magnetic levitation?
2. What is (nuclear) magnetic resonance imaging (MRI)?
3. Why are superconductors better than ordinary conductors for some applications?

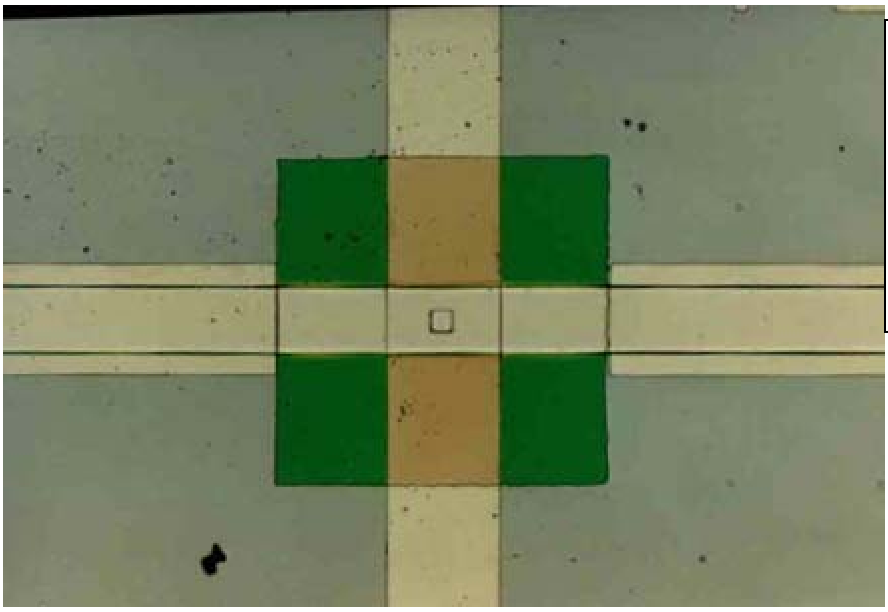
Modern high field clinical MRI scanner
http://commons.wikimedia.org/wiki/Image:Modern_3T_MRI.JPG

4. How are high temperature superconductors used in mobile phone base stations?
5. What is the difference between large scale and small scale applications?

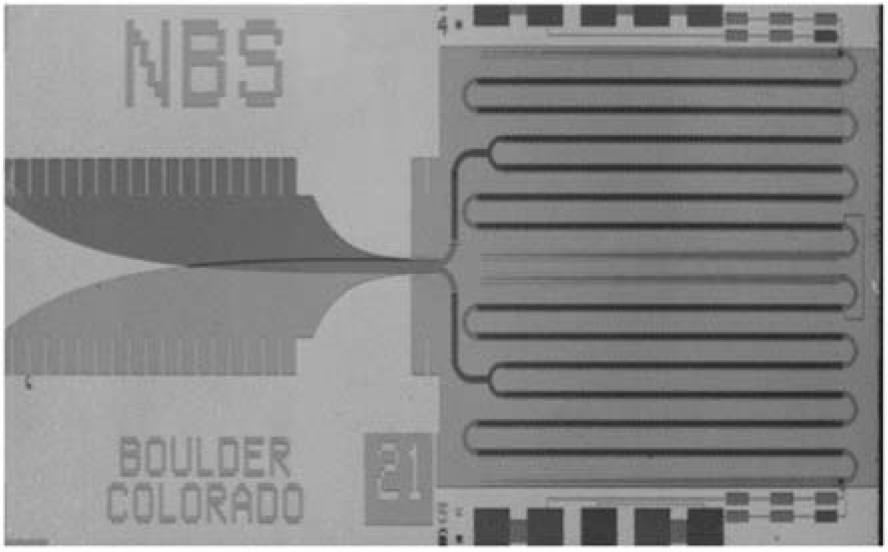
Suggested learning activities

These learning objectives can be connected to certain activities or scenarios for learning to take place:

1. Do the levitation demonstration and discuss how this can be used for practical purposes.
2. Discuss the impact on society resulting from the discovery of superconductivity.
3. Discuss what the world would look like if we had not discovered superconductivity yet.
4. Discuss if it could be possible not to have discovered superconductivity yet, and why.
5. Discuss possible benefits and drawbacks of each of the current applications.
6. Discuss possible uses of future applications, and their pros and cons.
7. Write a story from a future world where HTS applications are common.
8. Review the "futuristic story" of another pupil. Could this really happen? Why/why not?
9. Write a brief for a funding agency, explaining why you should get funding for a project you choose and describe, e.g. for fundamental research or for developing a certain application.
10. On behalf of the funding agency, consider the brief of another pupil. Does she/he get any money? Why/why not? What improvements could she/he make in order to get money (if she/he has not got it)?



Josephson junction
http://commons.wikimedia.org/wiki/Image:Josephson_junction_real.jpg



Superconducting chip used by NIST to define the volt. The chip contains an array of 3020 Josephson junctions and operates at liquid Helium temperatures. Microwave energy is fed to the junctions through the fin-guide on the left.
http://commons.wikimedia.org/wiki/Image:NISTvoltChip.jpg

Superconducting materials

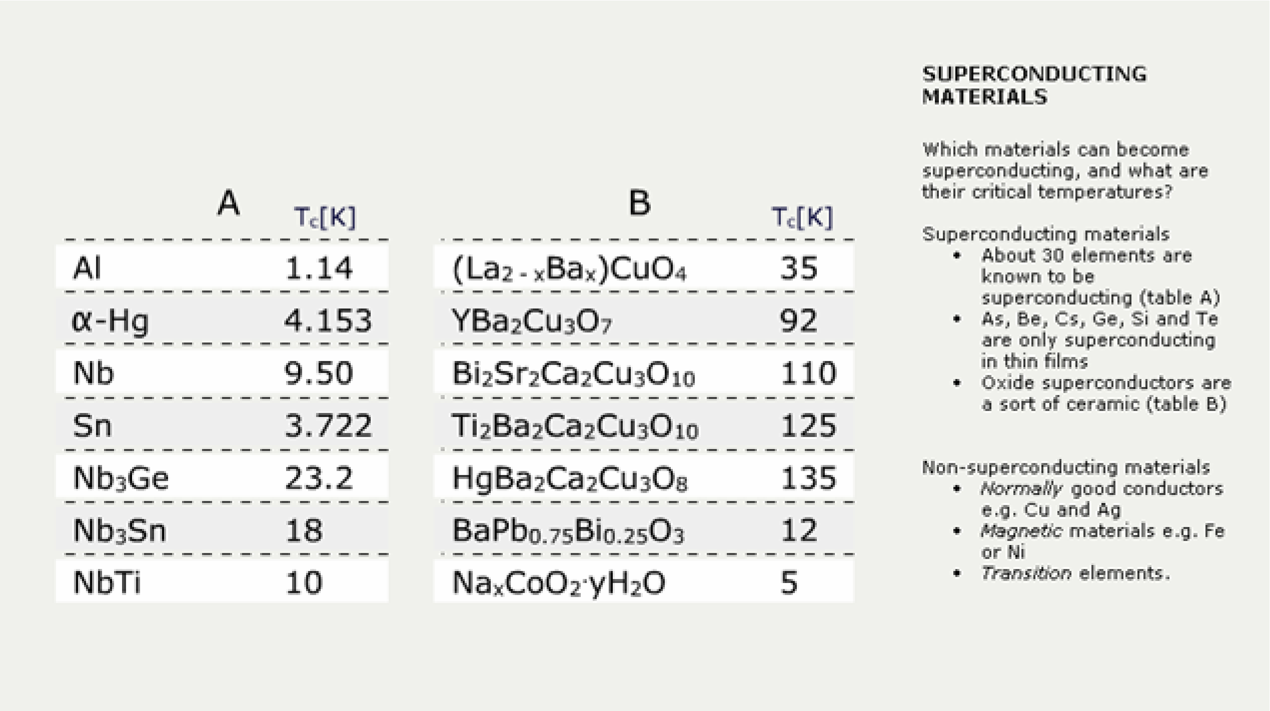
This module shows how metal elements were the first materials that scientists discovered having superconducting properties. The differences between superconducting materials are explained with reference to the positions of the relevant elements in the periodic system, and their chemical and physical properties.
The discovery of superconducting ceramics, cuprates or copper oxides, is discussed, and how their lattice structures allow supercurrent to flow more easily. Also a short explanation that to this day there is no proper theory for how high temperature superconductors actually work. Finally the discovery of a metal alloy with a higher critical temperature than any previously discovered type I superconductor is mentioned, and how this might affect the BCS theory.

- What materials are superconducting?
- Properties of superconductors
- Low-temperature and high-temperature superconductors
- Type I and type II superconductors
- Materials that are not superconducting
- Structure of ceramic copper oxides

Prerequisites

In order to work with the SUPERCOMET material, the pupils should already be able to

1. recognize that there exists a phenomenon called superconductivity
2. recognize that superconductivity relates to electricity and magnetism
3. recognize the characteristics of superconductivity (zero resistivity, zero magnetic permeability)
4. recognize the need for cooling superconductive materials below their critical temperature
5. recognize that the magnetic field lines go into and radiate from the poles of a magnet.



SUPERCONDUCTING MATERIALS

Which materials can become superconducting, and what are their critical temperatures?

A	T_c[K]
Al	1.14
α-Hg	4.153
Nb	9.50
Sn	3.722
Nb_3Ge	23.2
Nb_3Sn	18
NbTi	10

B	T_c[K]
$(La_{2-x}Ba_x)CuO_4$	35
$YBa_2Cu_3O_7$	92
$Bi_2Sr_2Ca_2Cu_3O_{10}$	110
$Ti_2Ba_2Ca_2Cu_3O_{10}$	125
$HgBa_2Ca_2Cu_3O_8$	135
$BaPb_{0.75}Bi_{0.25}O_3$	12
$Na_xCoO_2 \cdot yH_2O$	5

Superconducting materials
- About 30 elements are known to be superconducting (table A)
- As, Be, Cs, Ge, Si and Te are only superconducting in thin films
- Oxide superconductors are a sort of ceramic (table B)

Non-superconducting materials
- *Normally* good conductors e.g. Cu and Ag
- *Magnetic* materials e.g. Fe or Ni
- *Transition* elements.

Learning objectives

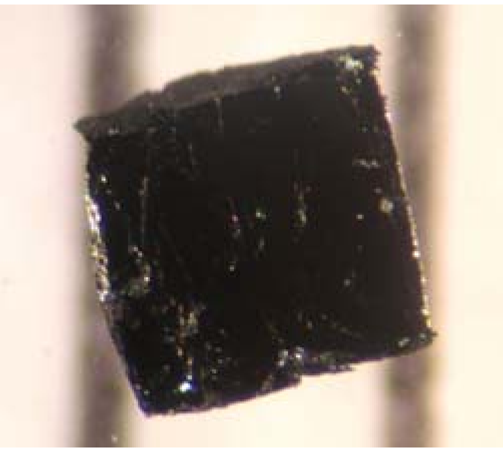
Based on work with this module, the pupils shall be able to

1. recognize the fact that almost all metals are LTS
2. recognize the fact that noble metals are not LTS
3. recognize the fact that HTS are ceramics and thus insulators above their T_c
4. recognize some major superconducting compounds/alloys like MgB_2, YBCO and BiScCO

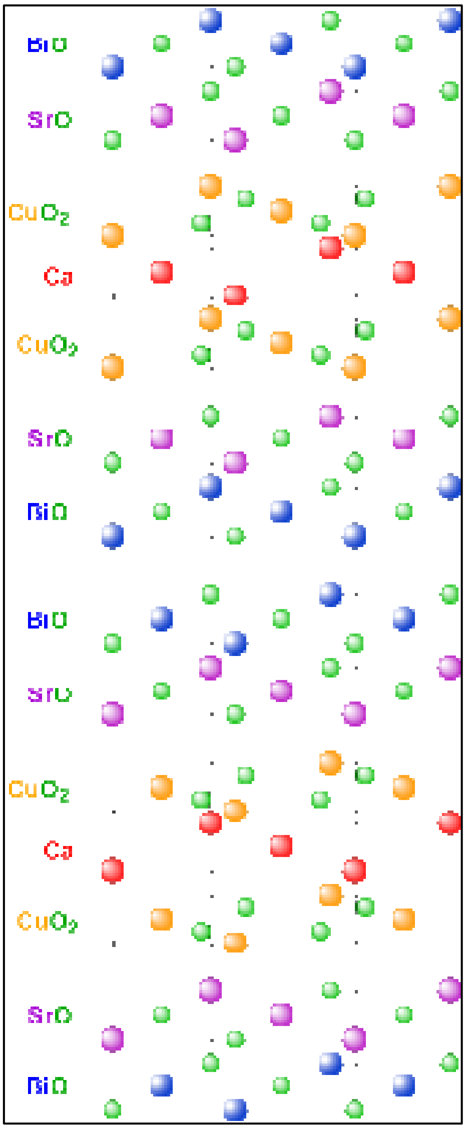
5. recognize the production processes for ceramic HTS and metallic LTS compounds
6. recognize some major challenges related to materials research and applications:
    a. testing the superconducting properties of large numbers of different materials
    b. making a cable from a ceramic material
    c. the necessary cooling systems require energy
    d. quenching due to excessive current, magnetic field or temperature
7. recognize that some superconductors are organic, and how they can be useful
8. recognize the different properties of important categories of superconductors:
    a. Layered non-cuprate
    b. A15-phase
    c. Chevrel-phase
    d. Heavy fermion compounds
    e. Fullerene based organic
    f. Organic salts
    g. Non-cuprate perovskites
    h. Cuprate perovskites

Knowledge testing

1. Can all materials be superconducting?
2. Will superconducting materials be superconducting all the time?
3. What makes a material superconducting?
4. What is the difference between a superconductor and a superconducting material?
5. What is so special about metals like gold (Au), copper (Cu), silver (Ag) and nickel (Ni), since they cannot become superconducting at all ?
6. What characteristics do these elements have in common: aluminum (Al), lead (Pb), mercury (Hg), tin (Sn)?
7. Why does the BCS theory explain how low temperature superconductors work?
8. Why doesn't the BCS theory explain how high temperature superconductors work?
9. Why can low temperature superconductors be either type I or type II, while high temperature superconductors can only be type II?
10. Why are low temperature superconductors used in particle accelerators, instead of high temperature superconductors?



A small sample of the high-temperature superconductor, Bi-2223 *http://commons.wikimedia.org/wiki/Image:BI2223-piece3_001.jpg*

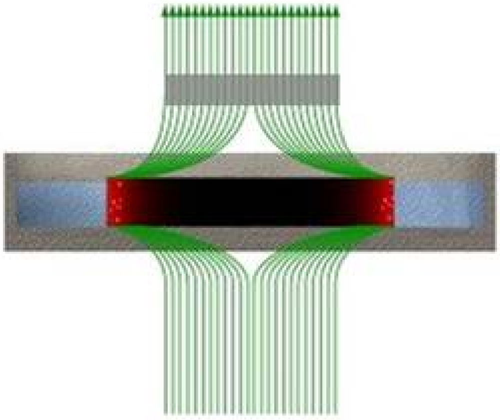


Unit cell of Bi-2212, a high-temperature superconductor *http://commons.wikimedia.org/wiki/Image:Bi2212_Unit_Cell.png*

Explanation of superconductivity

This module follows and extends the module 'Introduction to superconductivity'. The phenomena as well as the properties of superconductors will be explained and substantiated by theories, this means the step to the microsopic view.

- Different kinds of levitation experiments
- Microscopic view of Meissner effect
- Microscopic view of flux pinning
- Microscopic view of Josephson effect
- BCS theory for low temperature superconductors
- The search for a theory for high temperature superconductors



Prerequisites

In order to work through 'Explanation of superconductivity', the pupils should have achieved the learning objectives of the module 'Introduction to superconductivity' listed on p. 40.

Learning objectives

Based on work with this module, the pupils shall be able to

1. distinguish between different kinds of levitation experiments
2. describe the sequence of a Meissner experiment in detail
3. explain the Meissner-Ochsenfeld effect from a microscopic view
4. recognize that the Meissner effect cannot cause a stable levitation
5. describe the pinning experiment
6. explain the pinning effect using magnetic vortex lines and flux quantisation
7. elaborate the Josephson effect as a basis for SQIDs
8. recognize the BCS theory as an explanation for low temperature superconductors
9. recognize that there is actually no successful theory for high temperature superconductors

Knowledge testing

1. Name three different kinds of levitation experiments using magnets!
2. Draft the arrangement of a Meissner experiment. Describe the procedure step by step!
3. How is the perfect diamagnetism related to the levitation of a superconductor?
4. Why does the Meissner effect cause no stable levitation?
5. Think about achieving a stable levitation using the Meissner effect. How would you change the experimental setup?
6. Draft an arrangement of a pinning experiment. Describe the procedure step by step!
7. Explain the pinning effect using a microscopic view of superconductivity!
8. A pinned magnet is able to rotate above the superconductor. Explain this phenomenon!
9. What is a Josephson junction?
10. How can so called Cooper pairs cause a zero resistivity below the critical temperature?
11. Name some candidates for a theory for high temperature superconductors!

Activities with superconductors

This module shows further and challenging acitivities with superconductors. Although they demand a lot of technical skills, it is possible to arrange them in schools. To produce one's own superconductors can be a fascinating challenge in particular for competent pupils with interest in physics. Measuring the zero resistivity affords precise experimental work, maybe an encouragement for highly skilled pupils.

- Safety precautions
- Make your own superconductor
- Levitation experiments
- Measuring zero resistivity

Prerequisites

In order to work with this module the pupils should have a well structured knowledge of the contents covered by the previous modules, in particular of ‘Superconducting materials’.

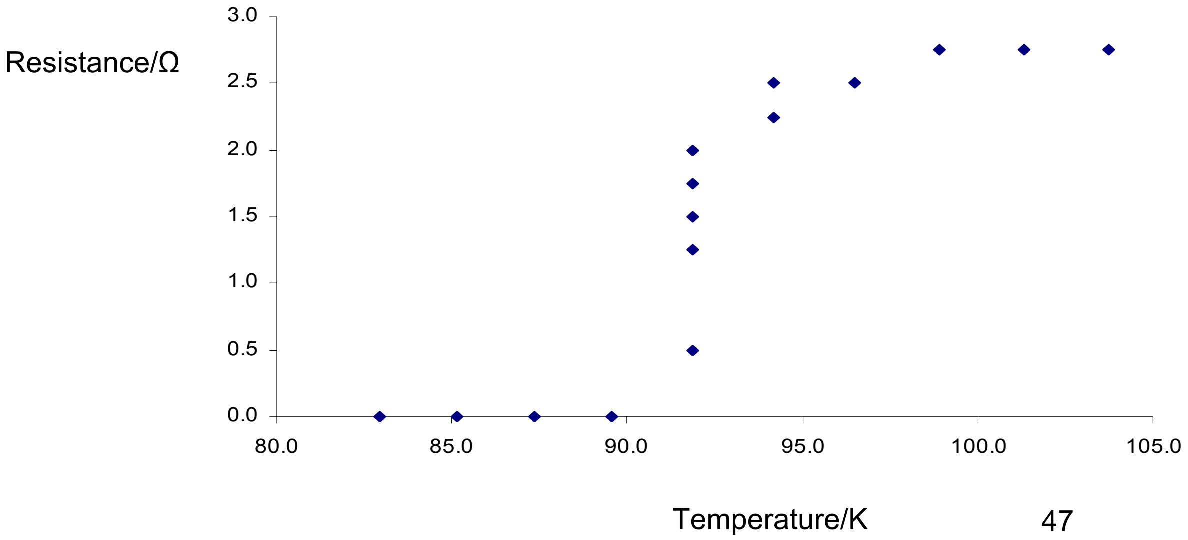
Learning objectives

Based on work with this module, the pupils shall be able to

1. pay attention to safety precautions for working with liquid nitrogen and strong magnets
2. recognize the production processes for ceramic HTS
3. point out the necessarity of this process to get a working HTS
4. explain how to test the quality of the produced superconductor
5. describe a measurement of the transition temperature of a superconductor
6. explain the four point contact method of this measurement

Knowledge testing

1. What are the special risks handling liquid nitrogen?
2. What are the safety precautions you have to follow in this case?
3. Which ingredients do you need in order to make your own superconductor?
4. Describe the manufacturing process step by step!
5. How can you test the quality of the produced superconductor?
6. Why isn’t it possible to determine the disappearing of the resistivity with a “normal” U/I measurement?
7. Draft the experimental arrangement of the four point contact method!
8. Explain the following diagram in your own words!



Examples of activities

Please note that all of the following activities must be adapted for use in your own classroom. They are only suggestions, designed to give you ideas to incorporate them in your own teaching. The SUPERCOMET 2 team welcomes your feedback on these activities – please post your comments in the SUPERCOMET website at www.supercomet.eu.

Effect of temperature on resistance of metals and of superconductors

Date : *Class:* *Lesson length: 110 mins*

Learning objectives

At the end of the lesson, pupils should:

- Understand the effect of temperature changes on the resistivity of metals
- Know that superconductors behave differently to other conductors
- Understand the difference between high temperature superconductors and low temperature superconductors
- Be able to recognize, and sketch, the shape of a temperature against resistivity graph for metals and superconductors
- Understand the meaning of Highest Critical Temperature

Materials and equipment required

- Enough computers to allow for one per three pupils
- LED
- Computers running SUPERCOMET e-modules online or of-line
- Liquid nitrogen and appropriate containers
- Copper wire coil with attached leads
- YBCO superconductive wire with attached leads
- 2 C batteries with holder
- 3 Volt flash light bulb with holder
- Voltage data sensor
- Computer attached to data projector and interactive whiteboard

Safety considerations

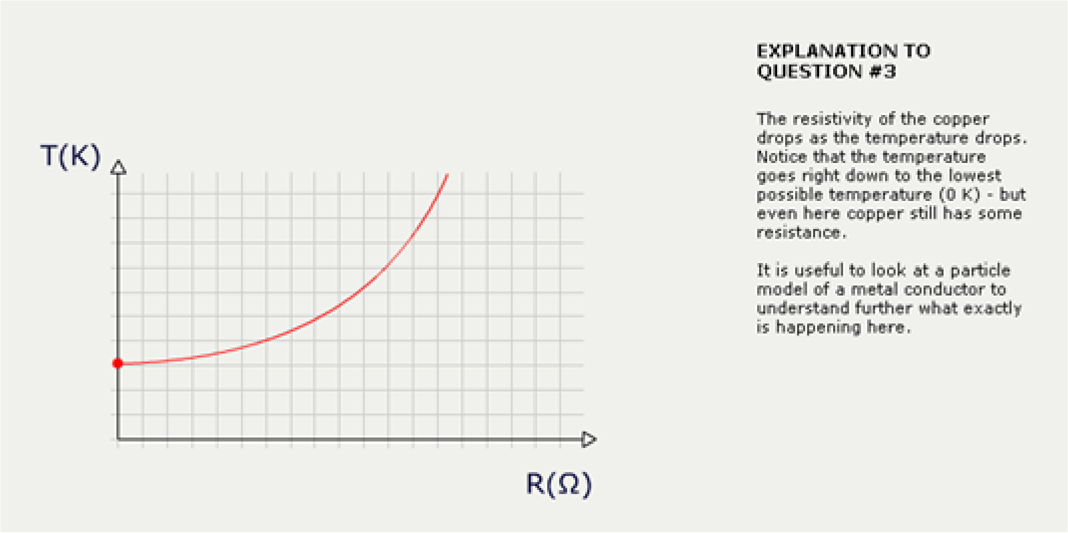
Handling liquid nitrogen is dangerous. Ensure that appropriate precautions are taken.

Time	Lesson outline
	Main issue to be addressed: how does temperature affect the resisitivity of different kinds of materials? Revision: specific resistance of different kinds of materials.
5 mins	Ask pupils to predict what will happen when the LED is cooled in liquid nitrogen. Demonstrate this by carefully lowering the LED into the liquid nitrogen for 10 seconds. Then watch what happens. Ask the pupils to explain what they have seen. Explain the effect of temperature on the resistivity of copper.

20 mins Ask pupils to predict the temperature vs. resistivity graph that you would find as you cooled metals. One pupil should sketch the graph on a template on the whiteboard. Connect batteries, semiconductor, and voltage data sensor attached to a computer. Put the semiconductor in the liquid nitrogen for 10 seconds, then take it out and let it slowly heat up. Share the data obtained with the whole group.

Introduce temperature coefficient.

35 mins In groups of four, ask the pupils to use the SUPERCOMET simulations of voltage vs. temperature, and, if necessary, the internet, to draw a voltage vs. temperature graph. Ask one pupil to mark this on the template on the whiteboard and compare with the results obtained by the formula.



EXPLANATION TO QUESTION #3

The resistivity of the copper drops as the temperature drops. Notice that the temperature goes right down to the lowest possible temperature (0 K) - but even here copper still has some resistance.

It is useful to look at a particle model of a metal conductor to understand further what exactly is happening here.

50 mins Ask one pupil in each group of four to join group A, one to join group B, one to join group C, and one group D. Ask each group to use data from the SUPERCOMET e-modules and the internet on the specific resistance of materials to sketch lines on a template to determine the highest critical temperature (T_c) of the following materials:

Group A	**Group B**	**Group C**	**Group D**
Copper	Mercury	YBCO	Carbon
Silver	Lead	BiSCCO	Rubber
Gold	Niobium	$Tl_2Ba_2Ca_2Cu_3O_{10}$	Porcelain

Each group should produce a graph showing their sketched curve and estimated highest critical temperature.

They should then look at the values given for their materials in the SUPERCOMET e-modules and discuss any differences

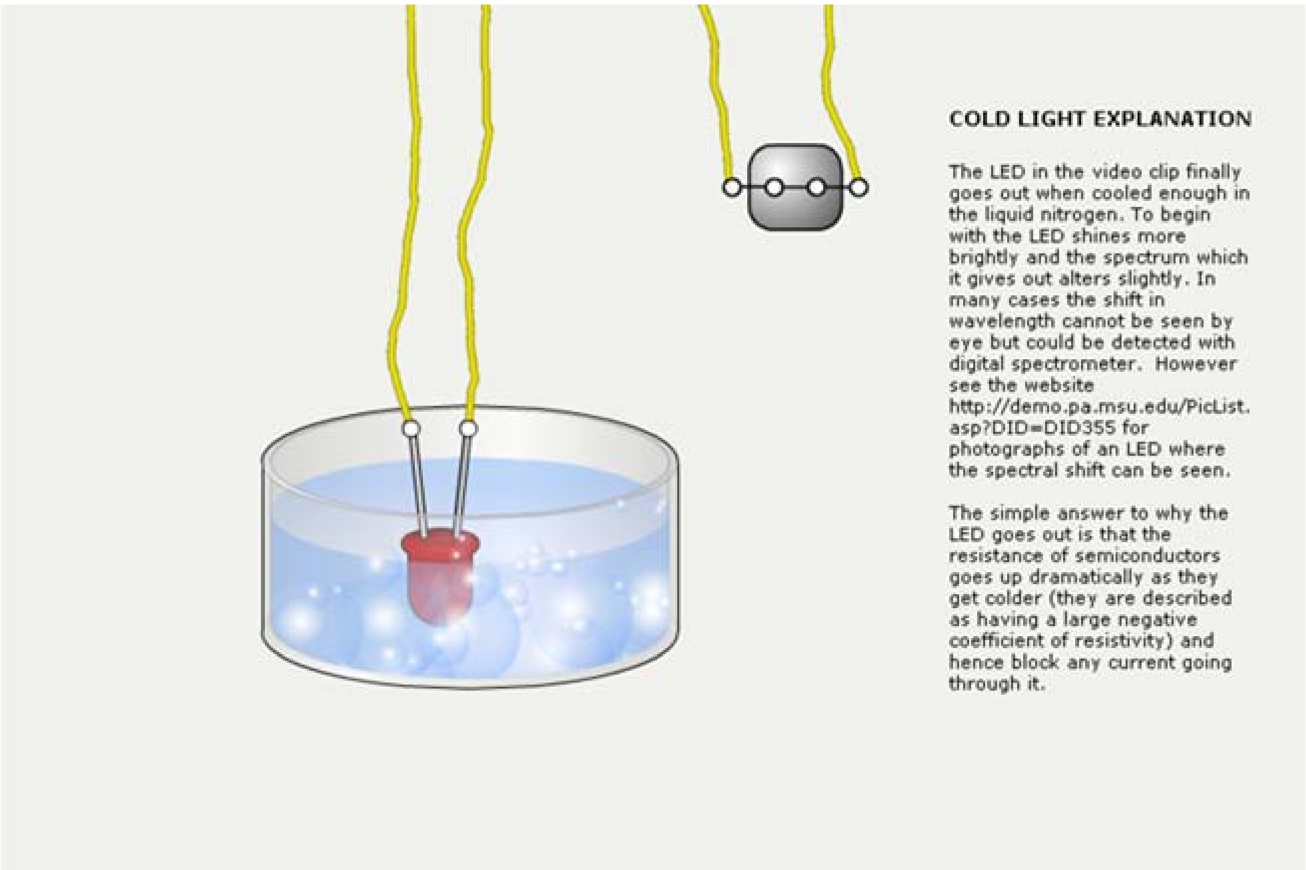
70 mins The pupils should return to their original groups to compare and discuss their findings. They should then use the SUPERCOMET e-modules to try explaining their findings.

90 mins The teacher asks one pupil from each group (A, B, C, D) to draw their three lines on the whiteboard and enter their estimated and the actual highest critical temperatures in a template provided.

The teacher should elicit conclusions reached and draw out the main lesson learnt.

Whiteboard Template (also give axes of temperature vs. resistivity graph)

	Material type	**Specific resistance**	**Estimated Tc**	**Actual Tc**
Group A	Copper			
	Silver			
	Gold			
Group B	Mercury			
	Lead			
	Niobium			
Group C	YBCO			
	BiSCCO			
	$Tl_2Ba_2Ca_2Cu_3O_{10}$			
Group D	Carbon			
	Rubber			
	Porcelain			



COLD LIGHT EXPLANATION

The LED in the video clip finally goes out when cooled enough in the liquid nitrogen. To begin with the LED shines more brightly and the spectrum which it gives out alters slightly. In many cases the shift in wavelength cannot be seen by eye but could be detected with digital spectrometer. However see the website http://demo.pa.msu.edu/PicList.asp?DID=DID355 for photographs of an LED where the spectral shift can be seen.

The simple answer to why the LED goes out is that the resistance of semiconductors goes up dramatically as they get colder (they are described as having a large negative coefficient of resistivity) and hence block any current going through it.

Suggested lessons on superconductivity

Introduction

Making the imperceptible perceptible – the art of demonstration.

Many physicists are intrigued by superconductivity, particularly when they see the levitation and suspension demonstrations. Pupils, on the other hand, may react differently: 'It's just like a magnet, isn't it? What's the big deal?' The 'big deal' is that they are not the same; it is, for instance, impossible to float a magnet on top of another without something to stop it shooting off.
An important component of the lesson, therefore, is the teacher's ability to make something small and apparently insignificant appear dramatic and thought provoking.

Safety – Demonstrations only

The practical part of the lesson can only be done by teacher demonstration as safety legislation prohibits pupils from handling liquid nitrogen (LN_2). For safety, if not for pedagogical, reasons, all the practical work must be tried out beforehand. Teachers who attend the related teachers' seminar will practise there and know the safety precautions necessary for working with liquid nitrogen.
IT IS ESSENTIAL THAT TEACHERS KNOW, AND FOLLOW, SAFETY GUIDELINES FOR WORKING WITH LIQUID NITROGEN.

Timing

Timing will depend on the class level. The demonstrations themselves will take only about 30 minutes. A sequence of learning activities has been suggested which could take up to two to three lessons: teachers must adapt them to suit their circumstances.

Suggested sequence of learning activities

1. Electrical properties of superconductors (using secondary sources: e.g. teacher's own account; books; e-modules...)
2. Demonstrations with liquid nitrogen and thinking tasks
3. Research in secondary sources
4. Follow-up tasks
5. Report on findings and teacher clarification

A possible sequence could be:
Lesson A – part 1: lesson B – parts 2, 3 and 4;
homework: continue with part 4; lesson C – part 5.

Preparation and ordering

Superconductor Demonstration kits and materials: See http://www.superconductors.org/Play.htm

The demonstrations here can be done with the basic kit. The company does, however, have larger kits which will allow measurements of critical temperature, critical current and critical magnetic field.
It is likely that liquid nitrogen is being used by hospitals, universities and industries near any city. Seek out a supplier who will deliver small quantities or make an arrangement with a local hospital or university. No more than a litre is needed.

Teachers need to be familiar with the contents of the e-modules as this is the main suggested secondary source for the pupils' own research. Other resources such as suitable internet sites and textbooks need to be selected in advance. Remember the safety precautions.

Terminology
Technically one should not refer to a material as a superconductor until it is cooled below its critical temperature. We have, however, adopted the convention of referring to the discs used in the demonstration as ‘superconducting discs’ even though they are not superconducting unless below their critical temperature. It is easier than saying ‘the disc which becomes superconducting when it is cooled below its critical temperature’ every time we want to refer to it.

Outline details

Part 1
Introduction to electrical properties of superconductors.

There is sufficient material in the e-modules to prepare a short introduction on the electrical properties of superconductors. There are ideas for comparing the graphs of resistance against temperature for an ordinary conductor and a superconductor – pupils can spot the rapid drop to zero resistance and ponder over what happens to the current when this happens (their instinctive reaction will be that it will become infinite – but of course it does not – they can think about why not). Limiting factors (critical current and critical magnetic field) could also be discussed from graphs available in the e-modules.

If teachers have the larger kits they can demonstrate the ‘zero resistivity’ state.
Teachers wish to take an historical approach and talk about how Onnes did the experiment several times because he could not believe what he was seeing – he thought there was something wrong with the apparatus!

A different starting point is a video of a Maglev train or a scanner in a hospital – with a statement that these both depend on the discovery of superconductivity.
Suggested time: 30 minutes

Part 2
Teacher demonstrations and thinking tasks. The demonstrations are of ‘strange electrical and magnetic phenomena’ which occur at low temperatures. The phenomena are:

- LN_2 is very cold – e.g. lettuce leaf and rubber in LN_2 become brittle (no superconductivity involved); ‘jumping’ of an aluminium ring on an electromagnet when current is switched on and increased jump after ring has been cooled in LN_2 (no superconductivity involved);
- the change in light of a light emitting diode (LED) (no superconductivity involved);
- the levitation of a magnet above a superconductor;
- the tendency of the levitated magnet to ‘return’ even when dislodged sideways, or to become stable at another location;
- the spinning of the magnet above the superconductor;
- the gradual return of a superconducting disc to the ‘normal state’, rather than an abrupt return;
- the suspension of a superconductor by a magnet, with a gap in between them (superconductor remains suspended when magnet is shaken gently from side to side).

Suggested time: half an hour.

Thinking tasks related to the demonstrations

The thinking tasks should encourage pupils to question what is happening, and begin to think of, for instance, why the aluminium ring jumps so much higher when it is cooled, what shape of magnetic field might give the behaviour observed in the levitation and suspension demonstrations, why the LED changes in LN_2.
There may be value in setting different tasks to different groups within the class, so that they report back.
Suggested time: 10 minutes.

Part 3

Research from secondary sources

After allowing pupils to draw on their own knowledge for these thinking tasks, some input will be necessary. Possible forms of input could be:

1. A system of ‘hints’ or questions from the teacher.
2. A set of carefully targeted book resources, with relevant pages marked.
3. Teacher explanation – building on what pupils have suggested.
4. Use of the e-modules where there is a discussion of all the questions posed.

Suggested time: half an hour in a lesson and a further hour for homework

Part 4

Follow-up work – homework – project work:

1. Use the e-modules to check ideas and extend them further.
2. Use the e-modules to write your own notes on what is meant by critical current, critical magnetic field and critical temperature.
3. Find out how phenomena related to superconductivity are being developed into technological solutions to problems.
4. Use the e-modules to explore explanations at the atomic level. The e-modules stick to what might be accessible to pupils in school. It does not contain any of the mathematics of quantum physics.
5. Use specific internet sites for further research.
6. Compare explanations of the levitation from three different sources – what are the similarities and what are the differences in the explanation? (This task can of course be extended to any of the phenomena and is a useful exercise in ‘don’t always believe everything you find on the net or in books’. Teachers might also discuss the reasons for this difference – part of which comes from the need to simplify a complex process for a lay audience).
7. When pupils get really enthusiastic about the topic they can research it not only through the e-modules and teacher-selected sites but through a ‘Google’ search on the internet. The following search phrases will be useful: ‘LED and liquid nitrogen; ‘Meissner Effect’; ‘Superconductivity’.
8. If you have access to the larger superconductivity kit, electrical measurements on the superconductor can be done. The teacher must handle the LN_2, but pupils can explain the design of the circuits and can interpret the results.

Part 5

Feedback from pupils and clarification

Pupils prepare a presentation of their ideas (posters/ short talks/ pamphlets/ explanations for future pupils – all are possible formats). Groups could be asked to include:

‘what we are sure of’;
‘what still puzzles us’;
Suggested time: one hour (depends on the format used)

Some input from the teacher will be needed – if only to reassure pupils that many of the explanations are way beyond the knowledge which pupils have at present and that much is not understood anyway – it is still a contested area.

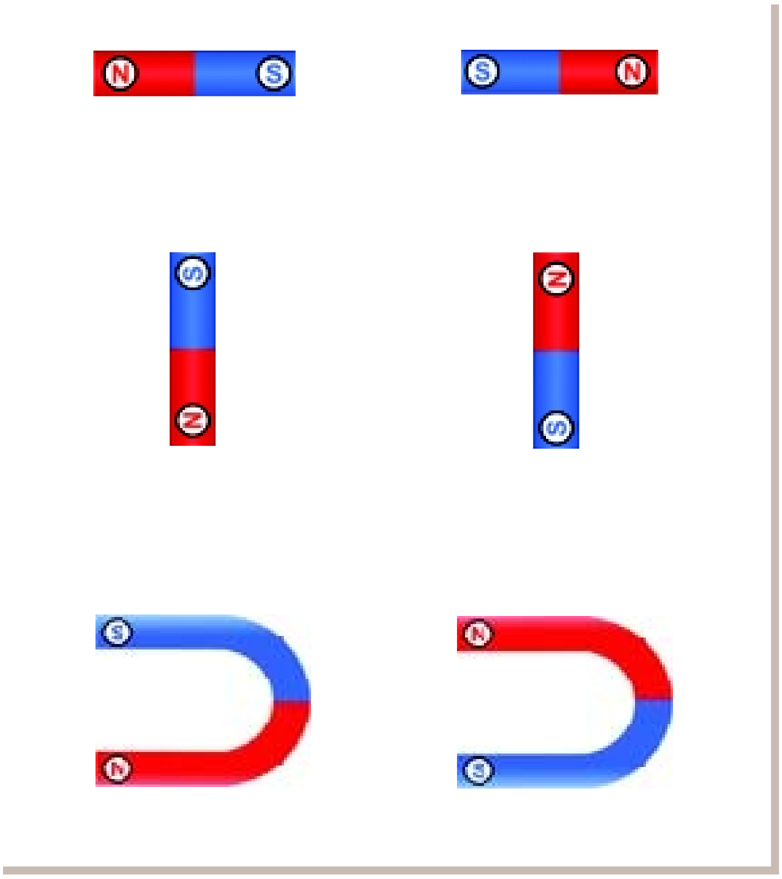
Give pupils access to one computer per group to work on their presentations.

The SUPERCOMET Teacher Seminar contains more hands-on information about the demonstrations.

For more information, visit **www.supercomet.eu**.

Worksheet 1 – Introduction to magnetic fields

Around the room you will find a number of magnets and sheets of paper covered with iron filings. These iron filings allow you to see the magnetic fields created by different types of magnets. Watch your teacher to see how she/he uses the iron filings to show the magnetic field of a magnet. Then, in pairs, draw the magnetic fields that you see in all of the following magnets:

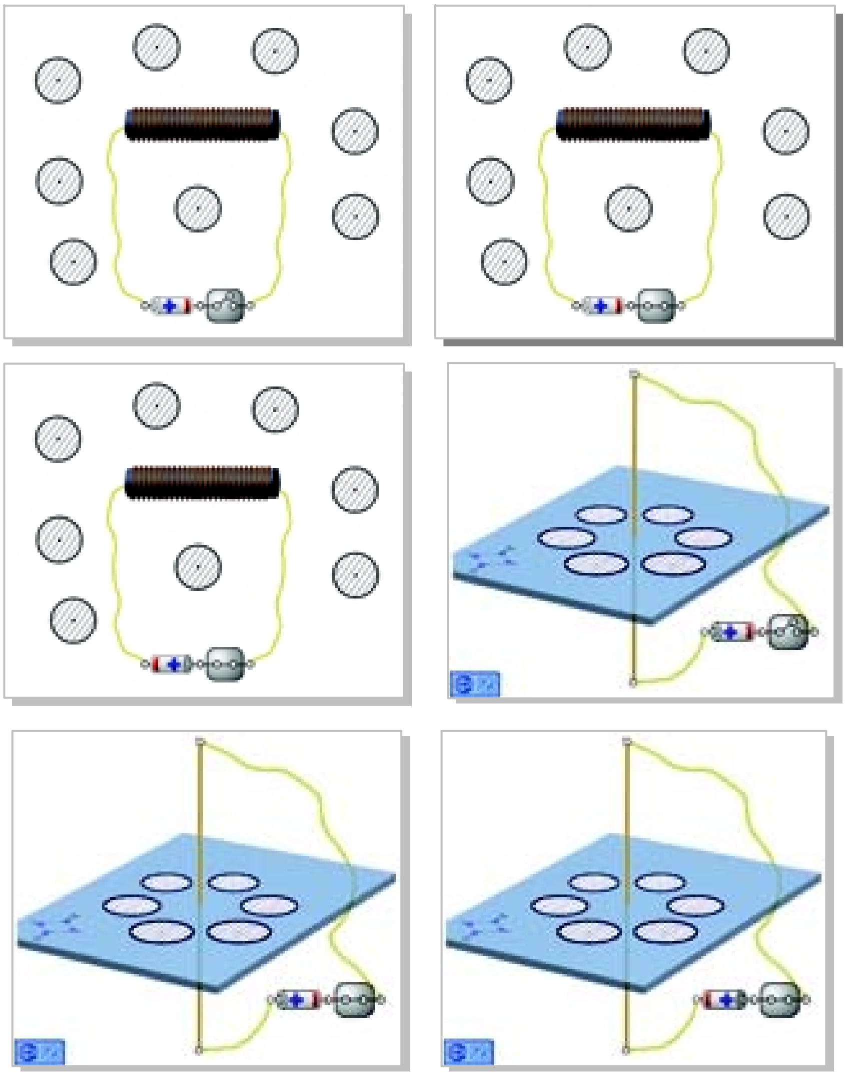


Example of worksheet on introductory magnetism

When you have finished drawing your magnetic fields, go to the SUPERCOMET e-modules and check the magnetic fields created by the different magnets there. Are the magnetic fields the same? If not, why do you think they may be different?

Worksheet 2 – Electromagnets, iron filings and compasses

Do the same exercise, this time using plotting compasses to examine the magnetic fields created around electromagnets.



Example of worksheet on introductory electromagnetism

Now use the SUPERCOMET CD-ROM to compare your magnetic fields with those you can find there. Are they the same?

Teacher note: be careful as the cells will get hot and run down very quickly. It might be preferable to use a power pack here.

SUPERCONDUCTIVITY – Stimulating worksheets for pupils

Michela Braida, Marisa Michelini, Udine (I)

1 Magnetic interactions

You have a magnet, a magnetic compass needle, a magnet, a piece of magnetite, an iron coin, a copper coin, an aluminum coin, an iron nail, steel staples, a plastic button, a shopping receipt, a table tennis ball, a toothpick, a small iron sphere.

1. EXPLORATION OF THE PHENOMENA. Bring the different objects to one of the magnet's poles one at a time, then change the pole and repeat the experiment. By observing what happens identify different types of interaction between the magnet and different objects.
2.

OBJECT	**TYPE OF INTERACTION**
Magnetic compass needle	
Magnet	
Piece of magnetite	
Iron coin	
Iron nail	
Copper coin	
Steel staple	
Aluminum coin	
Plastic button	
Receipt	
Table tennis ball	
Small iron sphere	
Toothpick	

3. What categories of behavior do you observe?

   Illustrate.

   A. ____

   B. ____

   C. ____

   ____

4. What determines the different types of behavior? (material, type of object, …)

   ____

5. When the interaction is attraction, which object attracts?

   Consider for example a magnet and some staples in the following situations

   A. Put the staples on the table and bring the magnet close

   B. Put the magnet on the table and bring the staples close

   Is it the magnet which attracts the staples or do the staples attract the magnet? (Explain)

   ____

   ____

6. Predict the interaction between a magnet and a ferromagnetic object. Explain.

   ____

7. Does the attraction between the magnet and the staples occur when there is contact or does it occur beforehand? Illustrate and explain.

   ____

8. Bring together two paper clips or two coins which were attracted by the magnet. Do they attract each other? ☐ Yes ☐ No

9. Predict what happens when you bring a magnet close

   ____

10. Describe what happens and give your explanation

    ____

2 Orientation lines and directions of departure

Place a sheet of transparent acetate under a magnet and trace its shape with a felt tipped pen. Arrange a group of compasses around a magnet. Draw with the felt tip the lines of orientation of the compass needles around the magnet with continuous lines to which each needle is a tangent. Remove the compasses.

1. In the space below reproduce the magnet and the distribution of the needles around the magnet with continuous lines to which each needle is a tangent.
2. Put another compass upon one of these lines. Where does its needle point?

   ____
3. Explain what these lines mean making reference to the way they were constructed.

   ____
4. Consider two of the lines of orientation.

   Do they maintain the same distance from each other? ☐ Yes ☐ No

   Do you think they would be the same on another plane, different from that of the table?

   ☐ Yes ☐ No
5. Illustrate in your own words how you represent orientation lines in the space around a magnet.

Remove the magnet. Distribute ferromagnetic needles uniformly on a sheet of acetate (iron filings or segments of steel wool for domestic use or similar tools). Place the magnet on the sheet of acetate in the same position as before. Observe how the steel filings arrange and orient themselves.

6. Is there any difference between the drawing of the lines produced based upon the arrangement of the compass needles and the distribution of the ferromagnetic needles?

   ☐ Yes ☐ No

   Discuss the similarities and differences. Formulate an explanation.

   Similarities ____

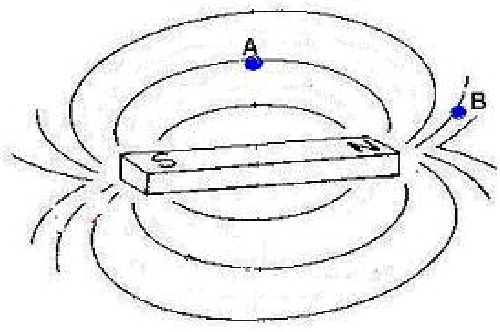
   Differences ____

   Explanation ____

7. Move the sheet of acetate with the magnet on top to various points on the table. Does the distribution of the segments of steel wool change? (respond and explain what you observe)

____

Let us consider the representation of lines of orientation of the compasses (field lines) of a magnet and let us place a steel ball at two points A and B as indicated in the figure below.



8. PREDICTION. If we let the ball move,
   - what is the direction of departure of the ball placed at A?
     (draw the figure and explain your prevision in words)

     ____

   - and that of B?

     (draw the figure and explain your prevision in words)

     ____

   - in your opinion do the field lines coincide with the departure direction of the steel ball? (Explain your reply)

     ____

9. PROOF. Place a ferromagnetic ball on points A and B. How does it move?

   (Discuss results)

   ____

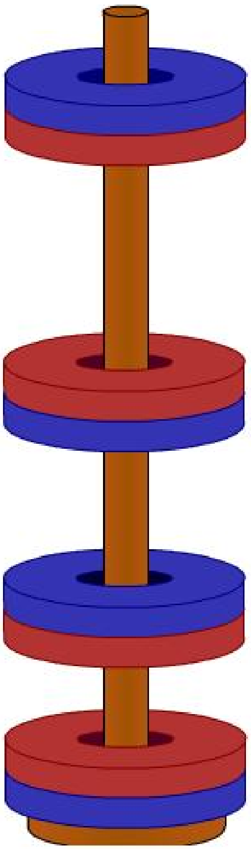
10. Do the directions of orientation and departure represent different aspects of the phenomena observed? (discuss the significance and explain your reply)

    ____

Suggested activity: measure of the magnetic field along a field line. Look at worksheets for Hands-on-Experiments 1, 2, 3

3 Suspension of magnets

You have four identical cylindrical magnets with a hole in the centre arranged on a wooden axis. The magnets remain suspended one on top of the other.



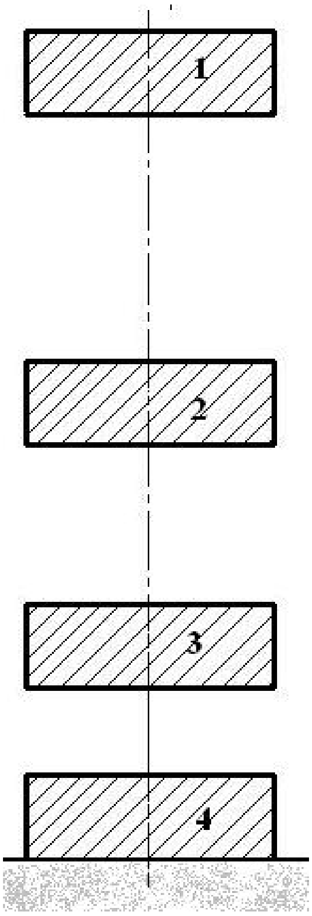
1. Imagine that you apply a force directed downward upon the upper disc, for example by pushing with your hand. Which of the following proposals do you think best describes the situation? Explain why.
    a. You expect to feel a “resistance” to the force that you are pushing downward.
    b. You think you will not be able to move the magnet from its position
    c. You think that the magnet will fall onto the one below.

2. Now push the upper disc downward with your hand. Describe what happens.

3. Compare your prediction with the proof. Discuss the results with regard to your expectations and give an explanation

In the figure below we have drawn up the four identical cylindrical magnets with holes in their centre in sections, arranged on a wooden axis.

1. What are the forces acting upon each disc? Show them on the figure below.



2. PREDICTION. Suppose we place the magnets on top of each other with the same poles facing (as they are now without the wooden axis passing through the middle). How do you think the magnets will arrange themselves? Explain your response.

____

____

3. PROOF. Now place the same poles of the magnets facing each other without the wooden support.
    a. What happens?

    ____

    b. Give an explanation of what happens.

____

____

4. What factors come into play such that the cylindrical magnets on the wooden axis remain suspended?

4 Falling in a copper tube

You have a copper tube which is 114 cm long with a diameter of 2,5 cm, a cylindrical magnet with dimensions such that it can pass through the tube, a steel cylinder of the same dimensions as the cylindrical magnet and a stopwatch.
Hold the copper tube in a vertical position and use the stopwatch to measure the time it takes for the cylindrical magnet and the steel cylinder to pass through the tube.

1. Let the steel cylinder fall through the copper tube. How many seconds does it take for the steel cylinder to pass through the tube?
____

2. Let the cylindrical magnet fall through the copper tube. How many seconds does it take for the magnetic cylinder to pass through the tube?
____

3. Is there a difference between the time it takes for the steel cylinder to pass through the tube and the time it takes the magnet? How do you explain this difference?
____

You have a copper tube of the same dimensions as before where an incision of 0,2 cm has been made lengthways along the tube, such that the incision is as deep as the tube wall. Hold the tube in a vertical position.

4. Suppose we let the steel cylinder fall in the copper tube. How long will it take to pass through the tube? ______________________
Explain your prediction____
____

5. Let it fall. How many seconds does it take for the cylinder to pass through the tube? ______________________

6. Do you notice any difference in the falling time of the same cylinder with respect to the tube without an incision? ☐Yes ☐No
Explain what you are experiencing or observing.
____

7. Suppose we let the cylindrical magnet fall through the incised copper tube. How long do you think it will take the magnetic cylinder to pass through the tube? ______________________
Explain your prediction:
____

8. Let the cylindrical magnet fall through the copper tube. How many seconds does it take for the magnet to pass through the tube? ____________________

9. Do the two cylinders act in the same way when they fall in the incised tube and the tube with no incision? ☐Yes ☐No

10. How do you explain what you have experienced or observed.

5 The jumping ring

You have a coil with a soft-iron core, extending form it a copper ring, a small chemist's furnace, a container with liquid nitrogen, white cardboard.

1. While the generator is off place the copper ring on the soft iron core. What happens?
2. Leave the copper ring on the soft iron core and turn on the generator. Describe what you see.
3. Leave the generator on. Do you notice anything?

   ☐Yes ☐No

4. Turn the generator on and off leaving the copper ring positioned on the soft-iron core. Describe what you observe.
5. When does the ring move from its initial position?
6. Explain the behavior of the copper ring when you turn on and turn off the generator
7. Place the white cardboard behind the coil with the soft-iron core, turn the generator on and off and mark on the cardboard the height reached by the ring.
8. h = ….
9. Heat the copper ring on a Bunsen burner for a few minutes and then put it on the soft iron nucleus. Turn on and turn off the generator.
   a. Describe what you observe.
   b. Does the ring jump higher or less than the previous time when it was unheated?

10. Place the white cardboard behind the coil with the soft iron core, turn the generator on and off and mark the height reached by the ring on the cardboard.
    h = ….
11. Suppose we immerse the copper ring in liquid nitrogen for some minutes in order to cool it and then position it on the soft iron nucleus. Predict whether the ring will jump:
    a. Higher or less than when it was at room temperature? Explain your response.

    b. Higher or less than when it was heated? Explain your response.

12. Position the white cardboard behind the coil with the soft iron core on the top. Immerse the copper ring in liquid nitrogen for a few minutes and then position it on the soft iron core. Turn the generator on and off and mark on the cardboard the height reached by the ring. The ring jumps: h = …
    a. Higher or less than when it was at room temperature?

    b. Higher or less than when it was heated?

13. Do you think that in some way the phenomenon is linked to the temperature of the ring. Explain your response.

14. Conclusions

6 Superconductors

You have a cylindrical magnet, a small superconductor pellet, a container with liquid nitrogen and a compass.

1. Before pouring the liquid nitrogen onto the superconductor place the compass on top of it. Where does the compass needle point?

2. Turn the superconductor and place the compass on top. Does the compass needle have the same orientation as in the previous case?

3. Place the magnet upon the superconductor. Remove the magnet and place the compass upon the superconductor. How is the compass needle oriented with respect to the two previous situations?

4. Does the compass needle orient itself according to a field that is not the Earth's field in the immediate vicinity of the superconductor? ☐Yes ☐No
5. How do you deduce this?

6. Pour the liquid nitrogen on the superconductor so that you cover the top of the superconductor. Wait until some of the nitrogen evaporates and the top of the superconductor re-emerges. Place the magnet upon the superconductor. Describe what you observe.

7. Place the magnet upon the paste of the superconductor, pour the liquid nitrogen on the superconductor and the magnet so that they are covered and wait until part of the nitrogen evaporates. Describe what you observe.

8. Compare the two previous situations. How do you explain the fact that the magnet remains suspended several millimeters above the superconductor?

9. Remove the magnet and the liquid nitrogen. Place the compass on the superconductor. How is the compass needle oriented?

10. Remove the compass, turn the superconductor and place the compass on top again. How is the compass needle oriented?

11. Is the compass oriented according to a field that is not the Earth's field in the immediate vicinity of the superconductor?

    ☐Yes ☐No

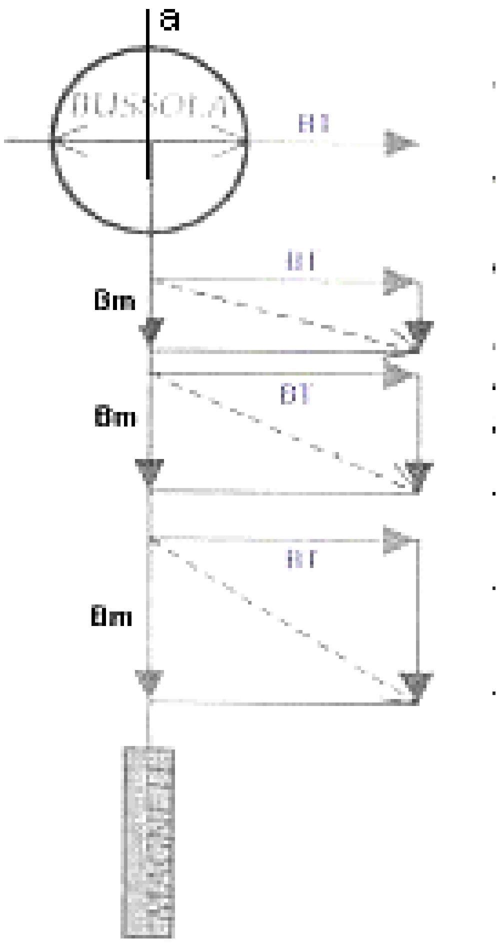
    How do you explain this?

12. What conclusions can you draw from these investigations?

Research experimentation

Francesca Bradamante, Marisa Michelini, Udine (I)

1. Measuring the magnetic field B with a compass



Objective: dependence on distance of the magnetic field along the longitudinal axis of a cylindrical magnet.

Method: measure in units of the **Earth's magnetic field (BT),** the magnetic field generated by a cylindrical magnet (**Bm**), based upon the deviation of a compass needle with respect to the direction of the Earth's magnetic field.

Materials: cylindrical magnet, compass, millimeter graph paper, pencil, ruler, adhesive tape.

Phases of experiment:

1. **Preliminary phase**: identify an area of the floor where BT is constant, using the compass.
2. **Organization of the system**:
   a) orient the graph paper so that the direction of BT corresponds to a line on the shorter side of the paper.
   b) place the magnet perpendicular to the direction of BT (along the line *a*)
3. **Measurement**:
   a) arrange the compass initially at 35 cm from the magnet along the line a and mark the direction of the compass needle.
   b) Find the value of Bm in units of BT: choose an arbitrary unit of the vector of the Earth's magnetic field BT (for example 2 cm) and identify the component Bm with respect to the direction taken from the compass at that point.
4. Gradually move the compass closer (at constant intervals of 2 cm) and identify Bm for each position.
5. Record the data in the table and analyze the dependence of the length of the vector Bm on the distance: (d = distance between the compass and the closest magnet pole; Ln = logarithm)
6. Represent the data in a graph

d **(….)**	**Bm** (……..)	**Ln (d)**	**Ln (Bm)**

2. Measuring the magnetic field B with a Hall Probe

Objective: dependence on distance of the magnetic field along the longitudinal axis of a cylindrical magnet

Method: direct measurement of a magnetic field generated by a cylindrical magnet (Bm) with a magnetic field sensor.

Materials: cylindrical magnet, magnetic field sensor, millimeter graph paper, pencil, adhesive tape.

Phases of experiment

1. **Preliminary phase**: determine the direction of the Earth's magnetic field BT and orient the sheet of the millimeter graph paper so that the direction BT corresponds to a line on the longer side of the paper.
2. **Organization of the system**: position the cylindrical magnet along the identified direction BT
3. **Measurement:** at regular intervals (1 cm) move the sensor closer to the magnet and note the values of the magnetic field B measured
4. Record data in the table and determine, by taking the difference between B and BT, the magnetic field Bm produced by the magnet in each position of the compass.
5. Analyze the dependence of the magnitude of the vector Bm on the distance and represent it in a graph
   (d = distance between the compass and nearest magnet pole; Ln = logarithm)

d (…..)	**B** **(….)**	**Bm** (…….)	**Ln (d)**	**Ln (Bm)**

3. Measuring the magnetic field B with the oscillation of a compass needle

Objective: the dependence on distance of the magnetic field along the longitudinal axis of a cylindrical magnet.
Method: measurement of the period of oscillation of a compass needle placed along the longitudinal axis of the magnet.

Materials: cylindrical magnet, compass, millimeter graph paper, pencil, adhesive tape.

Phases of experiment

1) **Preliminary phase**: determine the direction of the Earth's magnetic field BT and orient the sheet of millimeter graph paper so that the direction of BT corresponds to a line on the longer side of the paper.
2) **Organization of the system**: position the cylindrical magnet along the identified direction of BT
3) **Measurement:** at regular intervals (2 cm) move the compass closer to the magnet and measure the period of oscillation (measuring with a chronometer 5 or 10 oscillations and repeating each measurement 3 times)
4) Given that the period T depends upon the magnetic field B according to the equation:

$$T = k\frac{1}{\sqrt{B}}$$

   we use this to calculate (when k is a constant) the total magnetic field at the point where the compass is placed: $B \sim \frac{1}{T^2}$
5) Determine, by taking the difference between B and BT, the magnetic field Bm produced by the magnet in each position of the compass.
6) Record the data in the table and represent it in a graph
   (d = distance between the compass and the closest pole of a magnet; Ln = logarithm)

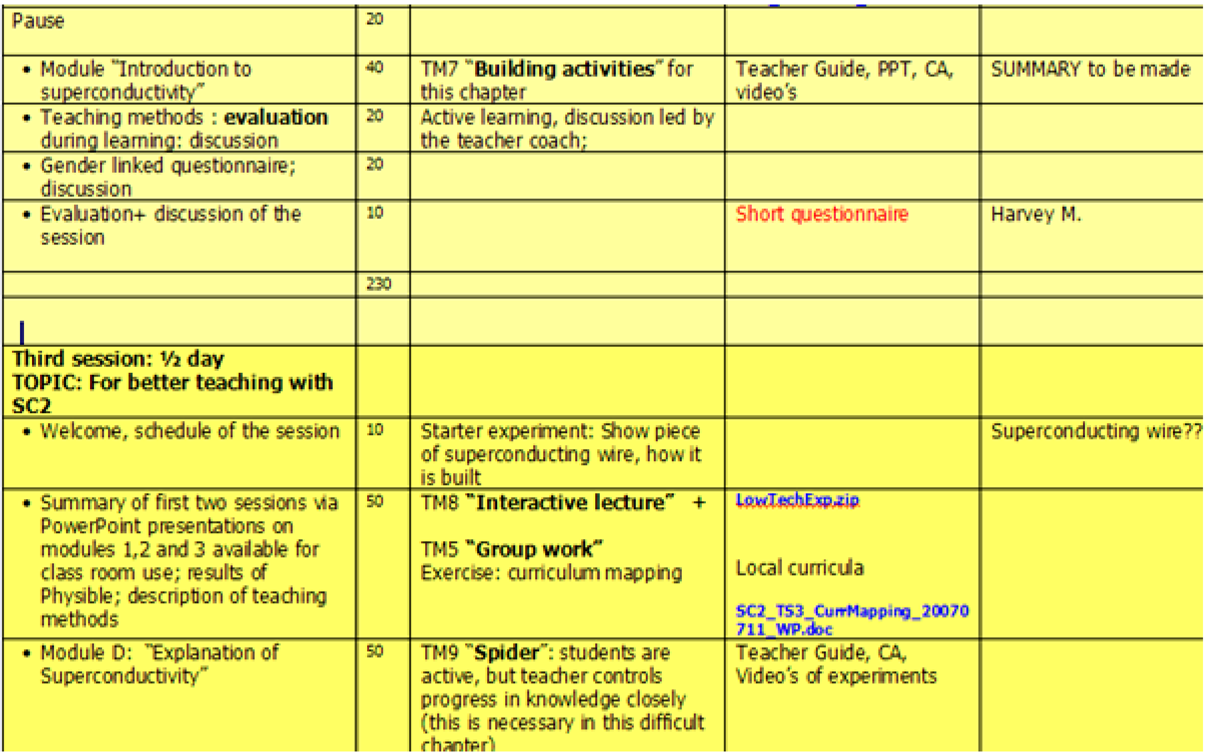
d (…..)	**T** **(…….)**	**B** **(….)**	**Bm** (…….)	**Ln (d)**	**Ln (Bm)**

Experiments – teacher seminar

The teacher seminar - overview

Wim Peeters, Antwerp (B)

In this section we introduce strategies to transfer the knowledge and the materials gathered during the SUPERCOMET 2 project both to the teachers and the pupils.
This transfer for the teachers is planned to take place in 2, 3 or 4 sessions, each a little less than 4 hours long. Two of them mainly aim at relevant "traditional" physics of electromagnetism and give an introduction to superconductivity, the third tackles more or less the theory of superconductivity, and during the last one the subject is applications and a summary of all teaching methods.



Pause	20			
• Module "Introduction to superconductivity"	40	TM7 "**Building activities**" for this chapter	Teacher Guide, PPT, CA, video's	SUMMARY to be made
• Teaching methods : **evaluation** during learning: discussion	20	Active learning, discussion led by the teacher coach;		
• Gender linked questionnaire; discussion	20			
• Evaluation+ discussion of the session	10		Short questionnaire	Harvey M.
	230			
Third session: ½ day TOPIC: For better teaching with SC2				
• Welcome, schedule of the session	10	Starter experiment: Show piece of superconducting wire, how it is built		Superconducting wire??
• Summary of first two sessions via PowerPoint presentations on modules 1,2 and 3 available for class room use; results of Physible; description of teaching methods	50	TM8 "**Interactive lecture**" + TM5 "**Group work**" Exercise: curriculum mapping	LowTechExp.zip Local curricula SC2_TS3_CurrMapping_20070711_WP.doc	
• Module D: "Explanation of Superconductivity"	50	TM9 "**Spider**": students are active, but teacher controls progress in knowledge closely (this is necessary in this difficult chapter)	Teacher Guide, CA, Video's of experiments	

(screenshot of the schedule for end of second and beginning of third session)

Since the materials are mainly digital these seminars should take place in a setting that is highly ICT based. Along with these digital sources, small low-tech experiments as well as high-tech experiments can be shown, so that a laboratory should be available.
The seminars for teachers aim to deliver all materials as well as methods to use these materials in a classroom situation. They are implemented in the sessions in a way that the teachers themselves can experience the mainly active teaching methods.
The teacher trainer should continuously switch between the two roles the participating teachers play: the professional educator, using methods to add knowledge and enthusiasm with his pupils, and the teacher, playing the role of student, and experiencing the activities. This way the theory becomes practice and the teachers can immediately adapt and adopt these strategies for classroom use. It is expected that a large proportion of the time will be given over to discussion.

Which materials are used during the sessions?

- The computer application, of course, remains the most important tool: it is used in all sessions, and all modules from it are studied in depth, in different ways.
- In addition, the teacher guide is used continuously with PowerPoint presentations giving additional information, both for pupils and for teachers, on superconductivity and on all aspects of teaching the subject. Meanwhile, the e-platform Physible will be used to increase interaction between learners and how it can be used as a library of teaching materials, ready for exchange.
- Of course, physics without experiments is not very lively: we suggest that a series of easy but nevertheless brain teasing experiments are used.
- During the teacher seminar we guide all participants carefully through all of these items and let them experience the materials in an intense way.
- A summary of all teaching methods is provided, as well as evaluation tools, additional questionnaires and media files.

Teaching method "rotating corners": Watch the group with two girls in green: they move clockwise from one small experiment to another (here: magnetic induction phenomena)
(Photo: SGC-Boechout-Belgium)

All information on the teacher seminar and the corresponding materials are available via the Simplicatus intranet.

Teaching methods – active learning

Quiz

Motivation of pupils

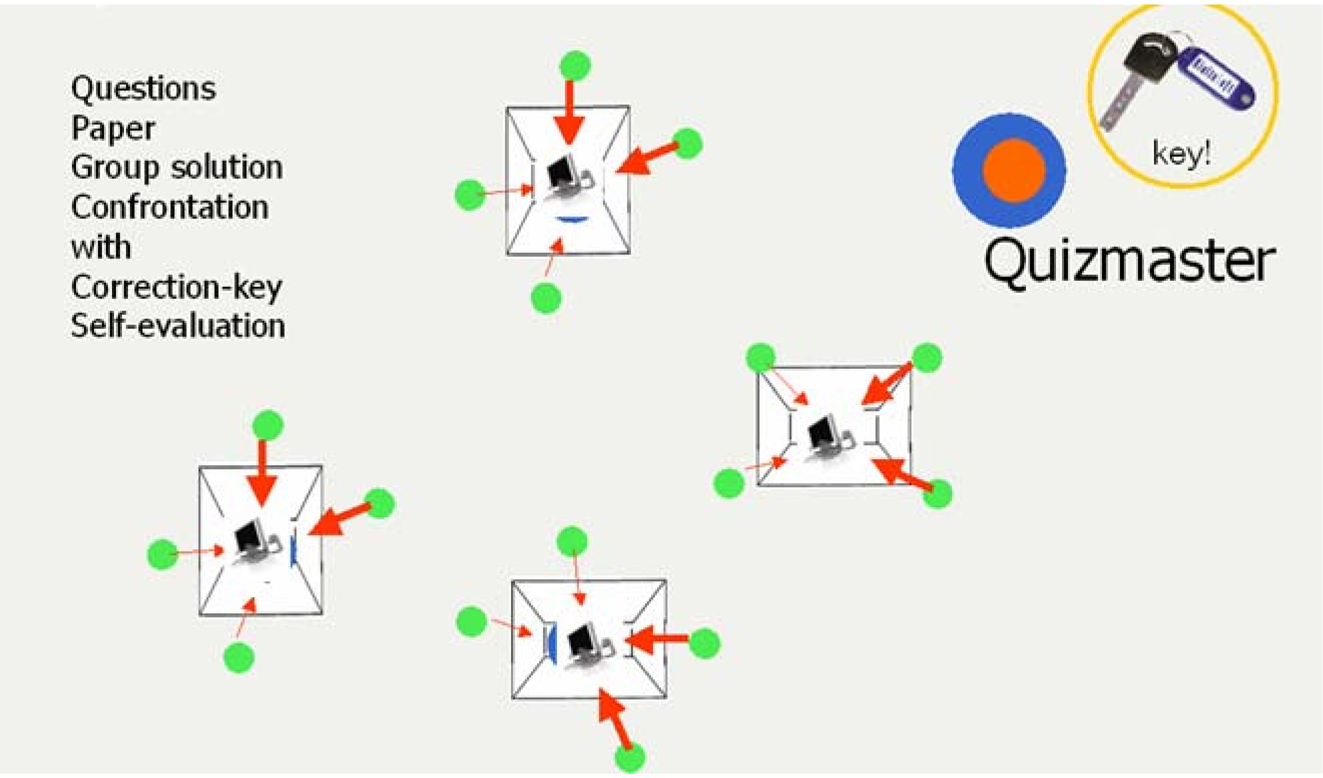
Game, points won, social interaction, discussion

Why?

Quick way of touching many subjects, many kinds of questions possible (also numeric, video, experiments, …), high variability in approach, in depth is possible.

Aims

- *Get started quickly*
- *Motivational*
- *Overview*
- *Discover hidden knowledge*



Method
Traditional format. Questions can vary widely in approach:

- with pictures, open questions, multiple choice
- about one module, about all modules, history
- differentiation is possible
- different teams

Pay attention to the “rewards” given. Evaluation: the success of this teaching method depends highly on the way it is done.

A/B-ACTIVITIES

Aims

- Pupils handle information in group, but independently, and pass that to each other.
- Pupils apply the content of their new knowledge in a creative task.

Method

Step 1: The aim of the task is explained. The task is rather general and conceptual. Pupils are divided in groups of 4 or 5. Each student plays a specific role: chairman, secretary, planner, … . The time is set. The specific roles are explained.

Step 2: Pupils carry out the first part of the task (A). Handling information (textbook, websites) and sources are essential here. Every student gets a different set of possible sources and a subject. Questions can guide them and stimulate discussions. They also bring in own experiences, knowledge and understanding.

Example:
1 Study and use of websites
2. How to select information
3. …and summarize it
4. Synthesis for the group
5. List of sources

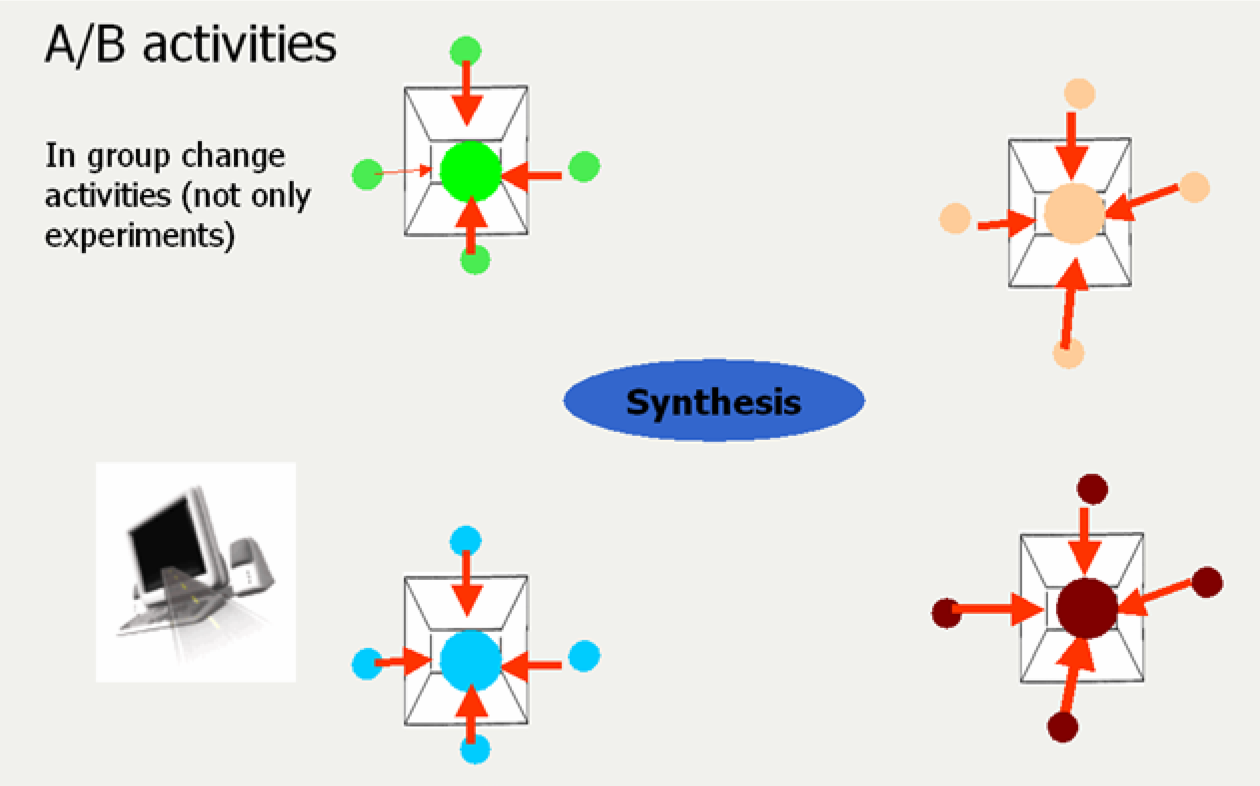
Step 3: Based on the previous phase (A) task B is given. This is more concrete, practical: the knowledge gathered in A is applied in B. The teacher mainly observes and and lets the pupils work as independently as possible.
Feedback by the teacher is given after the A/B tasks.

Examples

- applications of cooling systems
- examples of magnetism
- history of …..

Step 4: Each group presents the results of their specific task. Teacher and pupils give feedback and suggestions.

Evaluation of the product (how A is applied in B) and the attitude (during B) is possible.



A/B activities

In group change activities (not only experiments)

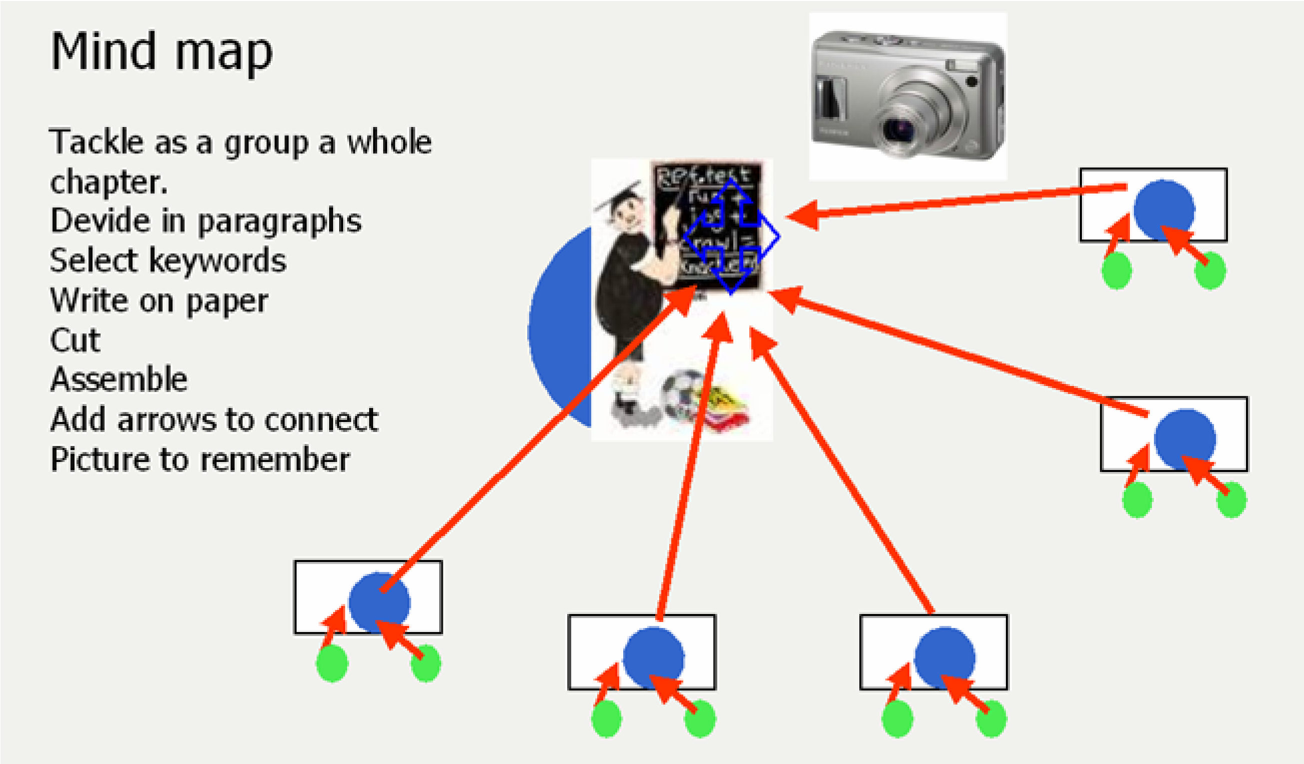
Synthesis

Mind map

The principle is well known
http://olc.spsd.sk.ca/DE/PD/instr/strats/mindmap/index.html

- Use single words or simple phrases for information
- Print words
- Use colour to separate different ideas
- Use of symbols and images
- Use shapes, circles and boundaries to connect information
- Use arrows to show cause and effect

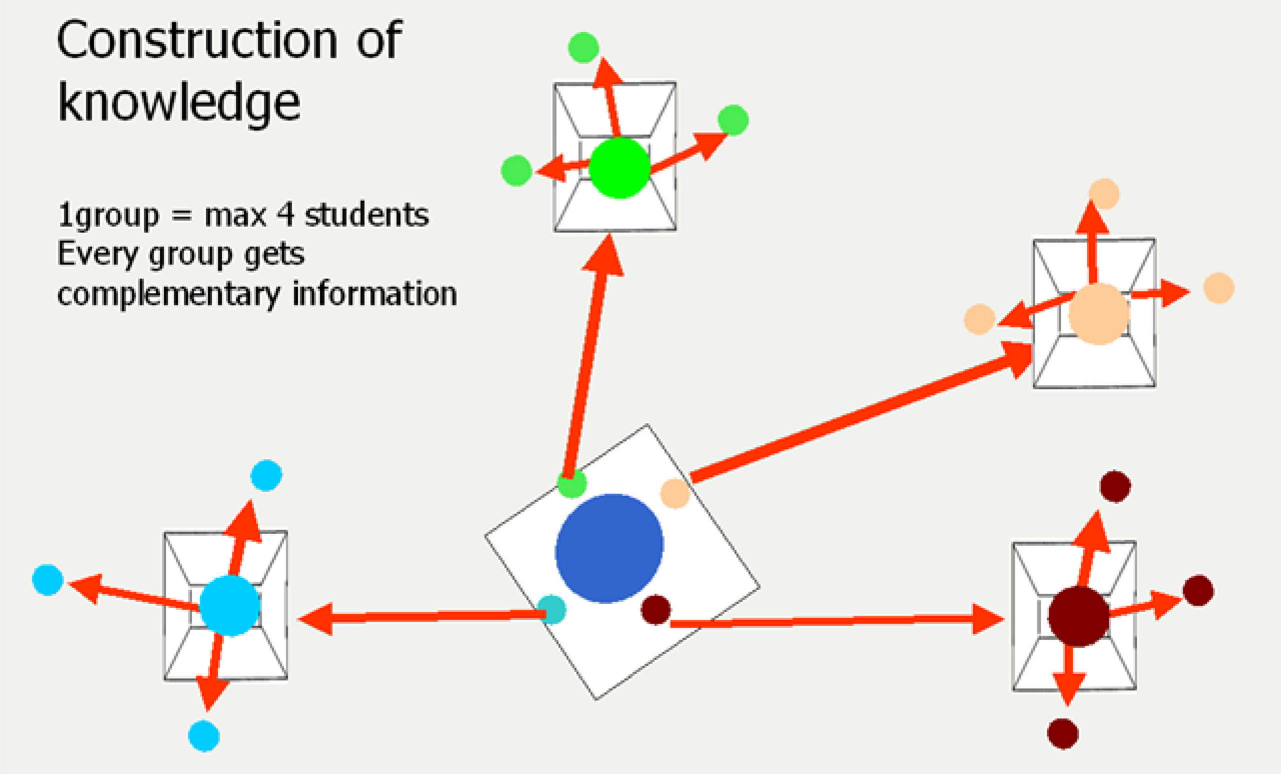
How can I adapt it?
For use with a large group as a brainstorming session of a whole class
Cut out strips and circles from cardboard. Discuss the main topic, write on a circle of cardboard and place on the middle of the mat. Each child gives a main idea about the topic, and goes away and draws this idea on another circle of cardboard. Each pupil also writes several words about their main idea on separate slips of cardboard. As pupils finish, the mind map is assembled on the mat with connections being made with the strips of cardboard. This can be stapled to the wall.



Mind map

Tackle as a group a whole chapter.
Devide in paragraphs
Select keywords
Write on paper
Cut
Assemble
Add arrows to connect
Picture to remember

Construction of knowledge



Construction of knowledge

1group = max 4 students
Every group gets complementary information

Aim
pupils are forced to work together because they all have different information.
Time : 1h or less

Method

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

Step 2: Each student studies his part. If necessary the teacher can add supporting questions and tasks.
Step 3: Exchange within the group: pupils bring in their work and assemble everything in one coherent unit.
Stap 4: The teacher tests whether all pupils have understood everything.

Examples

Different applications of a subject
It can be used for theory also
A typical sequence experiments/formula/exercises/applications

Rotating corners

Aim

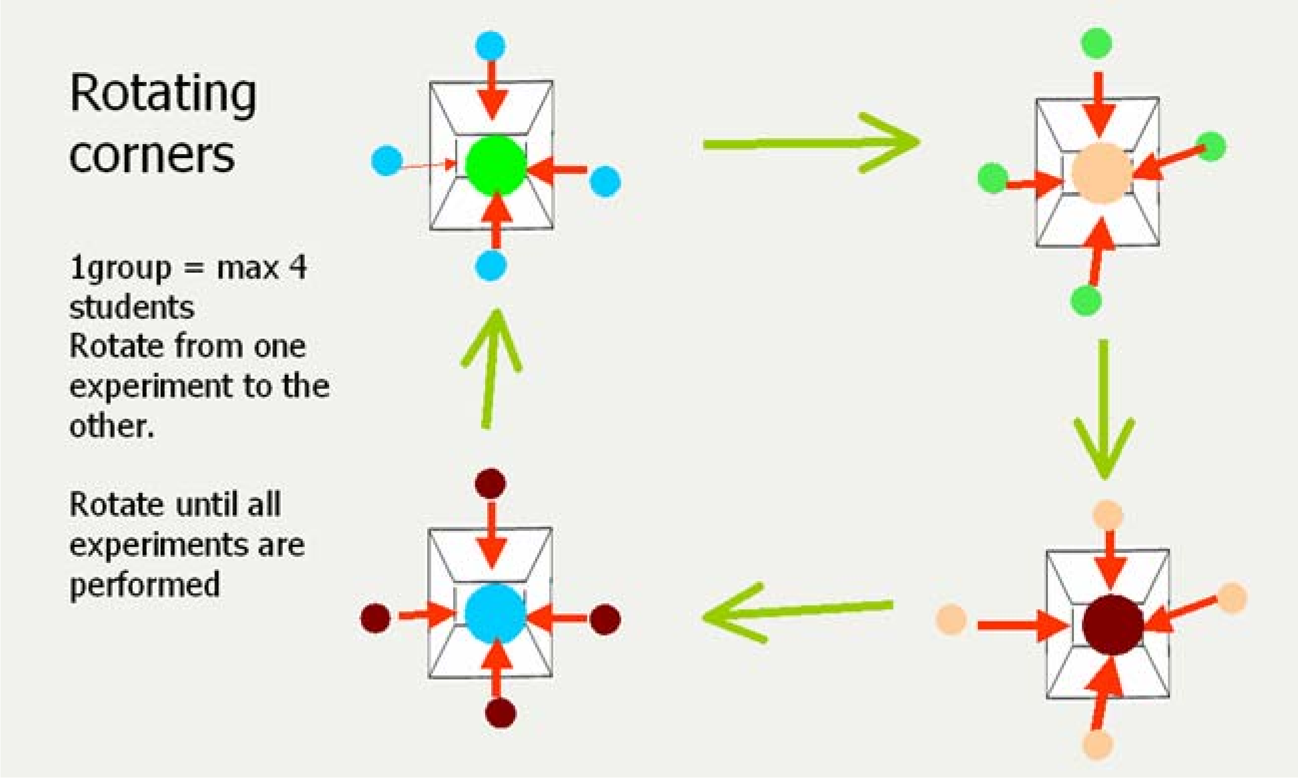
pupils in small groups do research on different aspects of the same subject
Time: 1 h or less

Method

Step 1: The teacher prepares different tasks for different groups. Every task should be carried out in different "corners/workspaces" of the room. All materials necessary are available in this corner.
Step 2: Pupils are divided in groups. They carry out a task and move to the next corner. All tasks should last more or less the same time.
Role play is possible here. Rules are set clearly: time, materials, solutions, writings, …
A bundle with all tasks can be handed out, but this is not necessary.

Examples

Series of small experiments on the same subject (electrostatics, dynamics, heat, particle model, relationship resistance-temperature, induction, optics, series of problems)



Lab experts

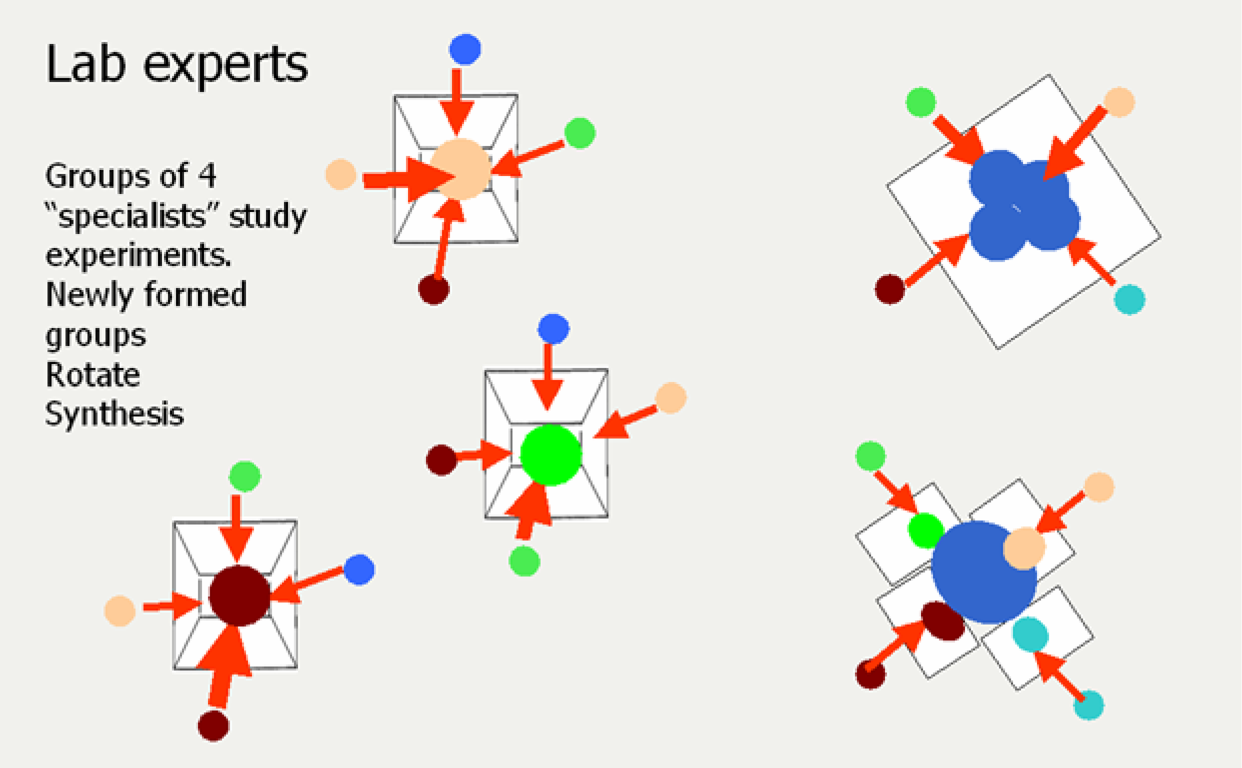
Aim

pupils become experts each in one (small/part of) experiment. They have to transfer this to their fellow pupils.
Time: 1h

Method

Step 1: formation of an “initial” group

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



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

Step 3: All experts put together the information they got and this becomes a small course. The group then formulates final conclusions, based on the whole of the information.

To keep an eye on the quality of the information, one can send two experts per basic group to each experiment. In an intermediate phase the teacher could check what each expert group has found/ one can also use a key with good answers /one could use a tutorial.

Subjects for this teaching method

Series of small experiments on the same subject (electrostatics, dynamics, heat, particle model, relationship resistance-temperature, induction, optics)
This is also useful if one organises a basic group for different aspects of a certain subject:
-Starter
-Basic experiment + data gathering
-Formula
-Problems
-Application(s)

Working with liquid nitrogen and magnets

Many practical demonstrations in the area of superconductivity require the use of liquid nitrogen. This is a dangerous substance and needs to be handled with great care:

- Use Dewar bottles or thermos flasks for transporting small quantities of liquid nitrogen, but NEVER SCREW THE TOP ON. Pressure could build up inside the thermos and cause the bottle to explode.
- Choose containers with care, avoiding ordinary glass or plastic, as these may shatter when brittle and cause injury.
- Keep the liquid nitrogen away from pupils.
- Demonstrate to them what can happen when materials are supercooled (for example, freeze then shatter a rose).
- Make sure that the liquid nitrogen does not touch any part of the body.
- Always wear safety goggles.
- Never touch any cooled objects such as superconductors or magnets. Always use tweezers which have been tested before to make sure they do not become brittle when cold.
- Wear insulating gloves.
- Make sure that the room you are working in is well ventilated.

Working with magnets

Some magnets (e.g. niobium magnets) can be very powerful and need to be treated with care:

- Always keep magnets away from computers, floppy disks, tapes and credit cards.
- Wear goggles in case two magnets are forcefully attracted and send off small shards of metal in the process.
- Make sure you do not get your fingers between two powerfully attracting magnets.
- Keep powerful magnets apart.

Levitation Experiments

Wim Peeters, Antwerp (B)

Practical resources required for activities

1. Liquid nitrogen – one Dewar flask with about 1 litre of LN_2
2. Styrofoam/polystyrene cups
3. Pyrex petri dishes
4. Pyrex beaker
5. Superconductivity kit. The simplest kit contains one small rare earth magnet, one larger rare earth magnet and a superconducting pellet. This is sufficient for demonstrating levitation and pinning.
6. A selection of light emitting diodes (LEDs) and cells to light them. They need to be on long leads so that they can easily be dipped into the liquid nitrogen.
7. A set of ring magnets on a stand (with a wooden rod going up the middle of them all so that they can be stacked repelling each other – have the wooden rod on a base so the magnets stack vertically)
8. Copper tube (0.30m)
9. Computers with the SUPERCOMET learning application with e-modules (online or offline)
10. Access to the internet (needed for online learning application)
11. Reference books

Demonstrations

Demonstration 1: Liquid nitrogen is very cold

Demonstrate how cold LN_2 is and that strange things happen:

- a lettuce leaf or flower because so brittle it shatters:
- Blue Tac nails because so hard they can be hammered into wood,
- a rubber tube which shatters when hit with a hammer.

Watch how long they take to come back to normal – why so long?

Demonstration 2: Jumping copper or aluminum ring

The jumping coil or jumping ring demonstration is well known and well documented. However the twist here is to cool the coil or ring to 77K therefore lowering the resistivity and allowing a far greater current to be induced. The impact of this on the strength of the field generated will be obvious. This also ties in well with the dropping magnets demonstration, and the link to superconductor levitation can be discussed as a combination of exceptionally powerful magnets and low resistivity.

The school is likely to have a demountable transformer kit. These kits nearly always contain a single metal ring (usually aluminum, but copper will do) which can be used as a ‘one turn’ secondary coil. Use a primary coil with lots of turns (the instructions will probably tell you which is the most suitable – if not, experiment to find out). When you connect the primary to the ac supply, the ring is shot up off the core.

Pour some liquid nitrogen into a polystyrene cup and put the aluminium ring into the liquid nitrogen until the liquid nitrogen ceases to bubble. Take the ring out and repeat the demonstration. The effect is dramatic – the ring is likely to hit the ceiling.

Safety Note: stand back – do not put your face in the line of fire on either experiment. Do not do this immediately under light fittings as in the second case the ring will hit the ceiling.

Demonstration 3: Cold light - LEDs in liquid nitrogen

As a light emitting diode (LED) cools the intensity may be observed to increase due to the increase in the band gap (energy difference between valence and conduction bands). This can also explain the frequency shift sometimes observed, indeed access to a digital spectrometer will allow you to record the spectrum at room temperature and near liquid nitrogen temperature. However if the LED is cooled enough it will go out, this can be explained in terms of electrons not having enough energy to cross the band gap or by the more familiar use of the notion that the LED is a semi-conductor and as such has a large negative temperature coefficient of resistivity.

The reason it becomes useful in the seminar is that the transition from conduction to valance band transfers energy either to a photon, which at a suitable frequency we see, or as lattice energy or phonons. Phonons are an important vehicle for describing ‘Cooper pairs’ as a mechanism for superconductivity.

Connect up a LED to an appropriate battery and get the class to note its colour and brightness - then immerse it into liquid nitrogen and watch for changes. The changes you will see will vary depending on the LED used. Therefore, use different ones. Some go out altogether (see the relevant e-module for an example) – some glow more brightly and there is often a slight change in the colour.

Demonstration 4: Dropping magnets

The kit required here is a length of copper tube, about 0.30m works well, a small niobium magnet and a piece of iron or steel of the same dimensions. When the steel is dropped through the tube it falls as one would expect, easily calculated from:

$s = \frac{1}{2}at^2$

When the niobium magnet is dropped through the tube a time of 4 or 5 seconds is observed.
Using a 0.30m length of copper pipe with an internal diameter of 0.014m and a niobium magnet of diameter 0.011m (height of the cylinder, 0.05m) you may consistently get a drop time of 5 seconds.
The aim of this demonstration is firstly to show that the effect is not a simple magnetic one since the copper is not magnetic.
Secondly it introduces the notion of an induced current, or eddy currents which in turn generate a field which opposes the motion. This effect is only noticed with magnets of exceptionally strength.
Finally a quantitative solution will require an understanding of rates of change, and, unless the participants have sufficient calculus, this could be left out.

Demonstration 5: Levitation of a magnet above a superconductor

These demonstrations are possibly not new but to allow the participants to have some hands on experience which they can relate back to the theory input and forward to their own teaching is not, we would argue, a bad thing.
The second of the two is perhaps less well known and would provide an interesting and challenging extension to a strong pupil.

Introducing the materials

rare earth magnets and superconducting disc

Before doing the demonstration with the superconductor and magnets, do introduce the class to the rare earth magnets (niobium). They have low densities but incredibly strong magnetic fields (they will pick up a lot of paper clips). They are fun in their own right. Keep them away from computers and keep your eyes on them - they are tempting ‘trophies’ and could easily go missing! They easily break, and stick very hard to iron materials: take care!!!

Superconductors are not very interesting to look at – slightly crumbly dark material which has no obvious properties. Show that the superconductor is not magnetic (try picking it up with a magnet – it won’t do it).
Also, it does not interact with another magnet (when it is warm)

Physics magic - Levitation

Levitation 1

Cut off the bottom of a styrofoam cup (or use a pyrex petri dish) and place the superconductor into it. Add the liquid nitrogen and wait until the bubbling has stopped. Using the plastic tweezers, bring up the smaller of the two magnets and place it on top of the superconductor. The magnet will stay floating above the superconductor. Get the class to note how high the magnet floats.

After a while the magnet will slowly get lower until it is sitting on the superconductor. Watch this stage carefully and note that it is gradual. (Let a few minutes pass before picking up the magnet and superconductor – they will take time to get back to room temperature).

Levitation 2

Now repeat the demonstration but this time put the small magnet on the superconductor first. Pour in the liquid nitrogen. After a while the magnet will levitate but not as far as in the previous demonstration. Make sure pupils notice this difference. Again watch the gradual dying away of the effect as the temperature increases.

Levitation 3

Cut off the bottom of a styrofoam cup (or use a pyrex petri dish) and place the superconductor into it. Add the liquid nitrogen and wait until the bubbling has stopped. Using the plastic tweezers, bring up the strong magnet and place it on top of the superconductor. The magnet will NOT stay floating above the superconductor. It is pushed away. Then, push the magnet down towards the superconductor, then it remains more or less stable. Get the class to note this clearly.
Try to turn the strong magnet, or to displace it: it does not work. It is stuck in the magnetic field.
This demonstration is similar to the levitation ones except in this case the superconductor is lifted up. Put the superconductor into a dish and pour in the liquid nitrogen. When the bubbling has stopped bring the larger of the two magnets near to the top surface of the superconductor. You will be able to lift the superconductor up. Notice there is a small gap between the magnet and the superconductor.
Repeat levitation 1 above, but this time push the levitated magnet to one side and release it – it moves back. Turn the magnet so that a different face is opposite the superconductor – it does not matter which pole is facing the superconductor, it always works.

Levitation 4

Now repeat the demonstration but this time put the strong magnet on the superconductor first. Pour in the liquid nitrogen. After a while “nothing happens”. Try to lift the magnet, watch the superconductor sticking to the magnet. The superconductor (or the magnet) can be turned as in the previous demonstration.

Thinking tasks

If you have not already discussed this as part of the demonstration, ask all pupils to think about why the liquid nitrogen forms bubbles – is it boiling like water boils? – if so what is the energy transfer process?

For all the levitation demonstrations and the lifting of the superconductor, you can ask:
1. Why does the effect go away slowly?
2. Why is the small magnet used for the levitation demonstrations and the large magnet used for lifting the superconductor?

Jumping ring

1. What was the difference in the two cases?
2. Why does the ring jump in the first place?
3. Why does it jump so much higher when it is cold?

(Pupils can draw on their knowledge of electromagnetic induction, the magnetic effect of a current and Lenz's law. They should also draw on their knowledge that the resistance of a normal conductor decreases as the temperature drops. Many pupils may be able to give an explanation of change in resistance in terms of reduced lattice energy.)

LEDs

1. What is happening?
2. Use your knowledge of conduction and valence bands to suggest what might be happening at the atomic level.

Levitation (when working on this, the group needs access to the set of ordinary ring magnets)

1. Why can you not make the ordinary ring magnets float one on top of the other, just like the small rare earth magnet floated on the superconductor? Why can it only be done with the wooden rod through the middle?
2. Draw the magnetic field between the 'ordinary' magnets when one is floating above the other.
3. Sketch what the magnetic field might look like under the levitated rare earth magnet.

(Pupils should be able to draw the fields between two repelling ordinary magnets, and to suggest that a similar shape field must be under the little magnet.)

Levitated magnet 'returns' even when dislodged sideways

1. Imagine what might be between the magnet and the superconductor to make the magnet return to its position when it is dislodged. What forces might be acting?
2. Why does the effect go away slowly?
3. In what way is this phenomenon different from what would happen with a pair of repelling magnets (as in the magnetic rings)?

Levitated magnet spins

1. Why does the magnet go on spinning for a little time after the blowing stops?
2. What stops the magnet spinning?
3. If the magnet were a cylinder, would it spin for a longer or shorter time? Why?
4. What theories do you have about why the magnet stays above the superconductor?

Lifting the superconductor

1. What are the similarities and differences between this and the levitation demonstration?
2. What is holding the superconductor close to but not touching the magnet?
3. Imagine what the magnetic field might be like between the two.
4. What theories do you have for how this is possible?

(In all these demonstrations pupils should be able to surmise that there must be some restraining/attracting force – as well as a repelling force. They might even imagine some lines of force going between the two – as you would have between two attracting magnets – and some lines of force being pushed out of the superconductor.)

Some notes about the demonstrations

The superconductors in the kit are type II superconductors. Type II show the pinning effect (where the magnet stays above the superconductor even when pushed out of the way) as well as the levitation effect. Type I show only levitation (the so-called Meissner effect). See the e-modules for the different magnetic properties of the two types of superconductor.

Do not make the mistake of assuming that type I superconductors are low temperature superconductors and that type II are high temperature ones. The classification into high temperature and low temperature is not much liked by people in the field and is somewhat arbitrary. The high temperature superconductors are merely the ones which have a critical temperature above 77K – the boiling point of nitrogen.

Hands-on magnetic and electromagnetic phenomena

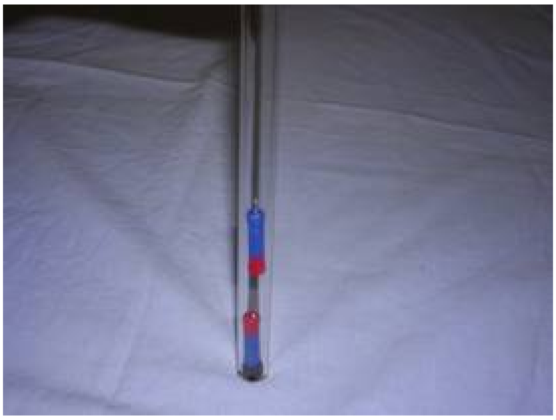
Barbara Fedele, Marisa Michelini, Alberto Stefanel, Udine (I)

1 – Magnetic rafts

Two magnets are placed upon two small polystyrene rafts floating on water. If we bring the north pole of one of the magnets near to the south pole of the other, we observe that the magnets attract each other. If we bring together the same type of poles (north – north or south – south) we observe that the magnet, which is able to move rotates 180 degrees in order to attach itself to the opposite pole of the other one.

2 – Distance in magnetic interactions

Distance influences the interaction between magnets. The further away the magnets are, the weaker their attraction is, until the point that they are not able to come closer, even when placed on rafts floating on water. When the magnets are close enough the attraction is strong: they attract until they touch.

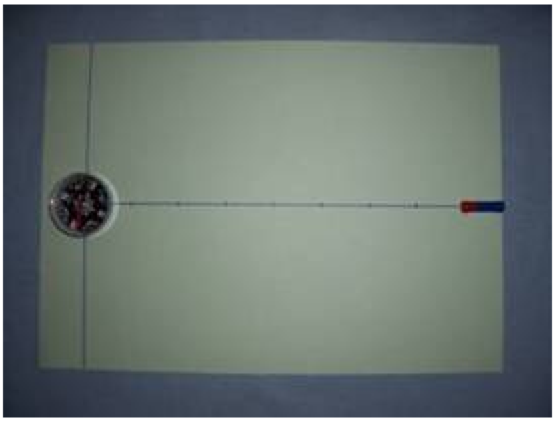


3 – Repulsion between magnets and distance: a measurement

Two magnets are inserted into a tube with the same poles facing each other. They repel. When the tube is placed in a vertical position, the magnet on top remains suspended as an effect of the repulsion between the similar poles of the two magnets. If we add small weights (of a non magnetic material) on top of the upper magnet, the distance between the two magnets is reduced observing an inverse power law.

4 – Behaviour of two springs under tension

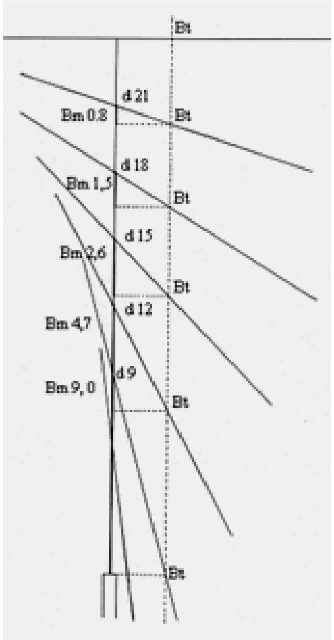
Two Newtonmeters are fixed at the extremes of two magnets placed in a small tubes, with their opposite poles facing each other. Pulling the two Newtonmeters, in order to separate the two magnets at a given distance, the lengthening of the springs of the two Newtonmeters is the same. We measure the lengthening of each spring D_L (or rather, the force exerted by each Newtonmeter) for the different distances of equilibrium d of the magnets and we find that, for small distances between the poles of the magnets, the product D_L*d^n=const, with n>2.



5 – The deviation of a compass needle brought close to a magnet

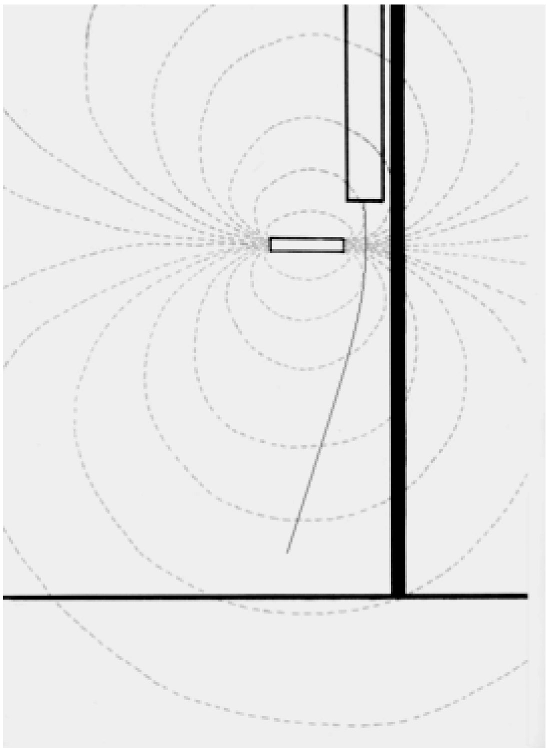
We place a sheet of what such that its smaller end points in the same direction as a compass needle placed on top of it. We place a cylindrical magnet at a fair distance from the needle of the compass, so that it remains perpendicular to the axis of the magnet. We bring the compass closer to the magnet. We record the direction of the compass needle at different distances from the magnet: it forms an angle which becomes more acute as it approaches the magnet. The projection of this direction along the direction of approach represents the component of the magnetic field caused by the magnet (Bm), with respect to the fixed component of the Earth's magnetic field (Bt). If we trace a parallel line along the direction of approach, we measure Bm in arbitrary units, measuring the length of the projection upon this from the direction of the needle. Bm grows rapidly as the distance (d) diminishes between the compass and the magnet.

We find that $Bm*d^3$= const.



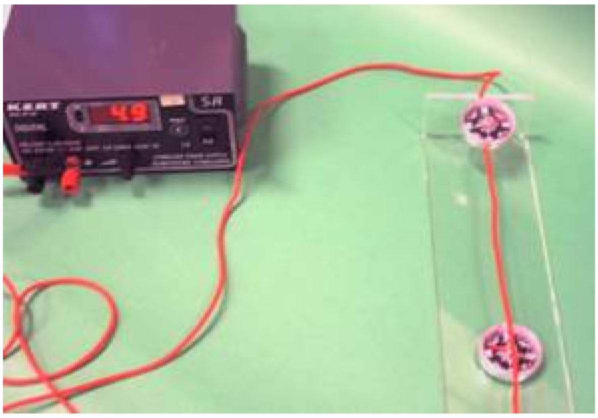
6 – Iron filings and magnets

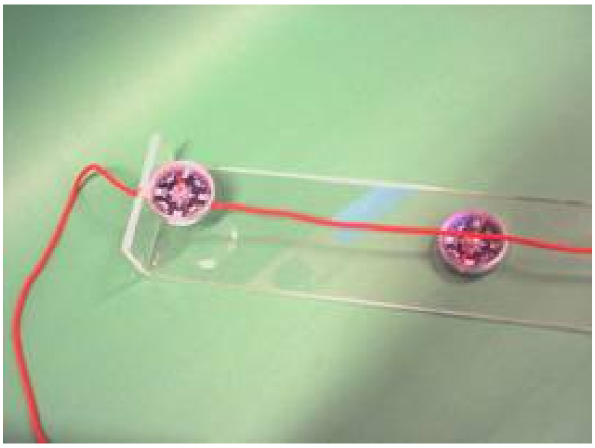
We spread some iron filings evenly inside a small plastic box (CD container). If we bring a magnet close we notice that the iron filings move and follow the movement of the magnet. If we place a magnet below the box, we notice that the iron filings align themselves according to a characteristic formation (see the drawing). In particular, the filings group around the two poles of the magnet: here the filings spread out in a ray; some filings lie flat on the surface while others stand either perpendicularly or obliquely. Space in the presence of a magnet acquires a new property: it becomes the base of a magnetic field. The disposition and orientation of the iron filings describes this. We obtain a representation of this if we place a sheet of acetate in a box (a flat transparent surface with small supports would be useful). If we change the position or even only the orientation of the box, we obtain the same representation. This is therefore characteristic of the effects of the magnet when considered in the surrounding space.



7 – Motion in a magnetic field

A steel ball is released on a descent, moving in a rectilinear motion on an horizontal plane. If the ball passes close to the pole of a magnet, its trajectory is deflected. Its velocity changes and this indicates the action of the force of the magnet-sphere interaction. The trajectory described by the steel ball is completely different from the magnetic field lines produced by the magnet.



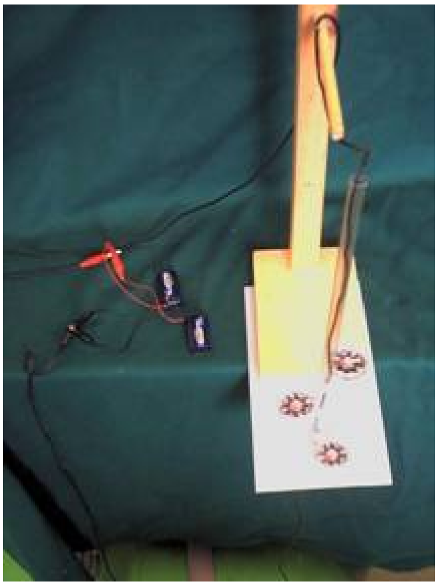


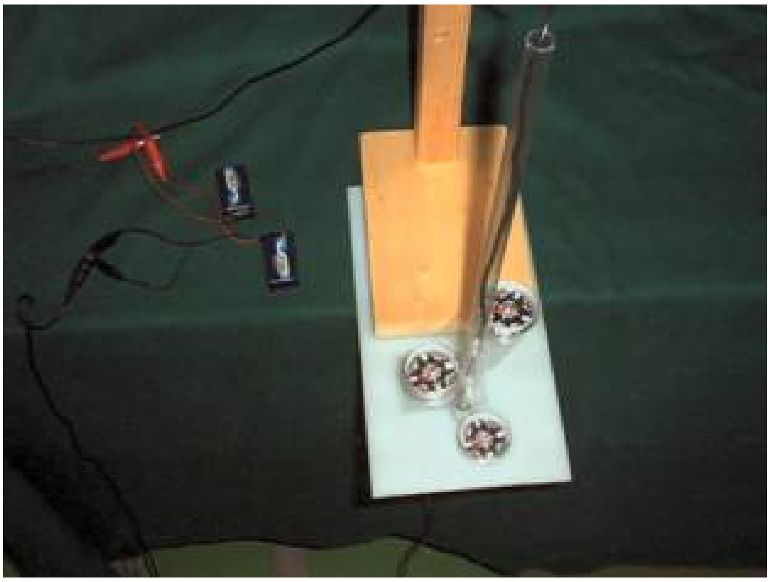
8 – Exploring the magnetic effects of anelectric current

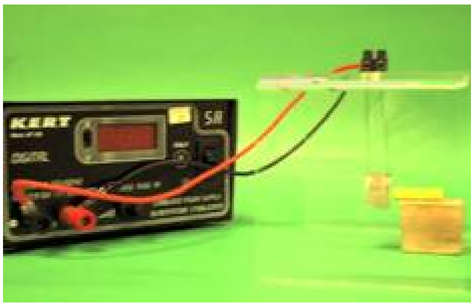
We place two or more compasses around a straight wire carrying an electric current (under, above, next to).
The needle of the compass: turns until it sits in an orthogonal direction with respect to the wire. The direction indicated by the needle is the opposite for the compasses placed beneath the wire, with respect to those placed above the wire.
If we reverse direction of the current in the wire the orientation of the needles is reversed in the compasses placed above and below the wire.
The magnetic effect of an electrical current is manifested on a perpendicular plane in the direction of the current. The magnetic field produced by a current extends above and below the cable. The direction of this is fixed when the direction of the current is fixed.

9 – The magnetic field produced by a wire conducting an electric current

A number of compasses are placed around a wire which is placed vertically. If no electrical current flows in the wire the compass needles are oriented in a north-south direction. If a current is passed through the wire the compass needles tend to move in such a way as to form concentric circles on a plane that is perpendicular to the wire with the wire at the centre.
If we place steel filings around the wire these orient themselves in such a way as to form concentric circles around the wire. The effect is much more intense in the areas close to the wire and also when more current passes through the wire.
The magnetic field produced by a straight wire carrying an electric current is always perpendicular to the wire.



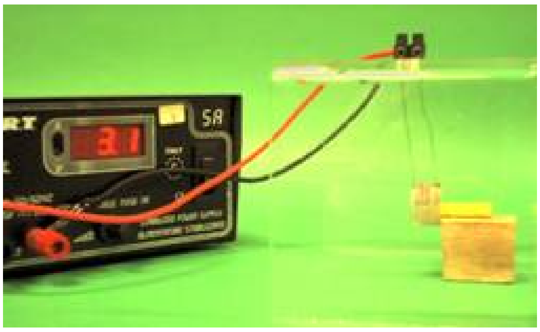


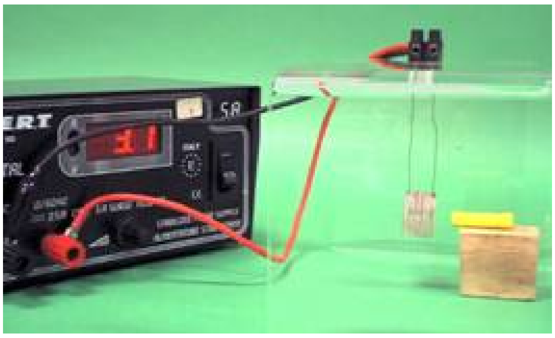


10 – Interaction between a magnet and a coil carrying an electric current

A coil carrying a current is attracted or repelled by a magnet according to the direction of the current.
The effect is amplified if we insert a core of magnetic iron material into the coil.

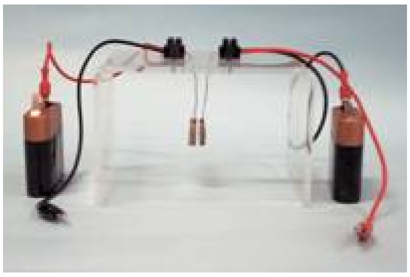
A coil carrying an electric current behaves as a bar magnet.

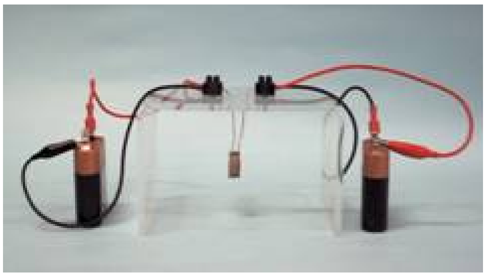




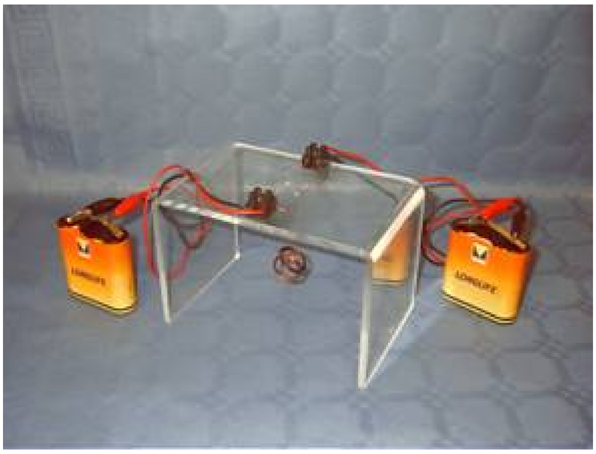
11 – Interaction between small coils carrying a current

Two coils, of a single turn, facing each other and each carrying a current attract or repel each other, in the same way observed with bar magnets depending on the direction of the current in each coil.





12 – Interaction between coils each carrying a current



Two coils, each with several turns, are placed together. When a current is passed through each they attract or repel according to the direction of the currents, as in the case of the previous demonstration. The effects are amplified with respect to those occurring in the previous demonstration.

The magnetic effects depend upon the number of turns on the coils.

How to make your own superconductor

Bernadette Schorn, Munich (D)

The critical temperature (T_c) of YBaCu superconductors is around 80K, which is high enough to use cheap liquid nitrogen (77K). Thus it is possible to experiment with these superconductors and even produce the pellets in school. The recipe for baking such superconductors reads like one for a cake: First take three different powders in the following quantities

yttrium oxide: 0,565g;
barium carbonate: 1,97g;
copper oxide: 1,19g.

Mix them thoroughly and crush the mixture in an agate mortar until you get a consistent powder.

This powder then must be pressed into pellets.

After the pellets have been baked in a special oven at 950°C for more than one day, they have to be cooled step by step for one more day.

These pellets have to be crushed, pressed and baked once again, but now for a longer time. After the baking process, the superconductors can be tested, e.g., in the form of the following exciting and easy-to-perform experiments:
If the sample is very small, it is better to use a ring magnet and let the cooled sample float above. The sample will heat above T_c within a few seconds and then stop floating.

Another possibility is to put a big self-made sample into liquid nitrogen. If a strong magnet floats above the sample, the sample passes the test of superconductivity.

For the Meissner-Ochsenfeld-Effect the magnet is laid on the sample at room temperature. According to classic laws, no floating should happen as the magnetic field does not change any more. But after cooling the sample the magnet will float. This shows that superconductivity is more than perfect diamagnetism.

Measuring the transition temperature of a superconductor

Gren Ireson, Loughborough (UK)

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http://www.iop.org/EJ/article/0031-9120/41/6/012/pe6_6_012.pdf?request-id=yjmEIR973BG1Y-Qd3Ai7Kg

Abstract

This paper present the methodology and results for a simple approach to the measurement of the transition temperature of a superconducting material, in a pre-university laboratory session, using readily available apparatus (and some liquid nitrogen).

Introduction

This journal recently carried a report (Ostermann and Ferreira, 2006) on a Brazilian approach to the preparation of high school teachers to teach superconductivity to their pupils. However, what many readers may not be aware of is a European project addressing the same issues, SUPERCOMET 2, which involves 15 European countries.

SUPERCOMET (Superconductivity Multimedia Educational Tool) is based around a series of multimedia modules covering electricity, magnetism, electromagnetism and superconductivity, (Earle et al, 2004). This work is published in English, Italian, Norwegian and Slovene. Now SUPERCOMET 2 is taking this work forward and will include both a revised teacher seminar and a hands-on kit to allow teachers to up-date their subject knowledge, explore opportunities for school based activities and borrow the kit to carry out school based activities. During 2007 this work is expected to be published in all participating country languages.

As part of the teacher seminar participants measure the transition temperature of a YBCO[1] superconductor. What follows sets out this methodology and presents results from the last teacher seminar, held in Loughborough, UK during March 2006.

Measuring resistance

In theory the measurement is simple, at what temperature does the resistivity of the material drop to zero? Resistance measurement is familiar to all high-school physics pupils through the application of Ohm's Law[2] and this forms the basis of the method used. Unfortunately the typical set up as shown in figure 1, cannot be used.

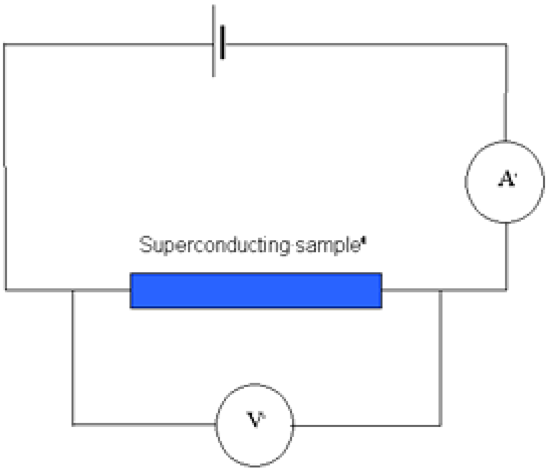

Figure 1: simple resistance measurement

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[1] YBCO or $YBa_2Cu_3O_7$ was discovered in 1986 and was the first superconductor to have a transition temperature above that of the boiling point of liquid nitrogen (77K).

[2] Whilst YBCO is a non-metal it can be approximated to an ohmic conductor in the same way that non-metal high value resistors are.

In order to measure when the resistivity drops to zero, i.e. when a current flows through the sample with zero potential difference across it, we need to use a 'four point contact', see figure 2: *There are four leads connected to the sample. Two of them are used to provide a current, I, through the sample. The second pair of leads are then used to measure a voltage, V,. Since no current flows in the second pair of leads the contact resistances will not matter. The resistance of the part of the sample between the second pair of contacts will be R = V/I by Ohm's law* (Annett, 2004).

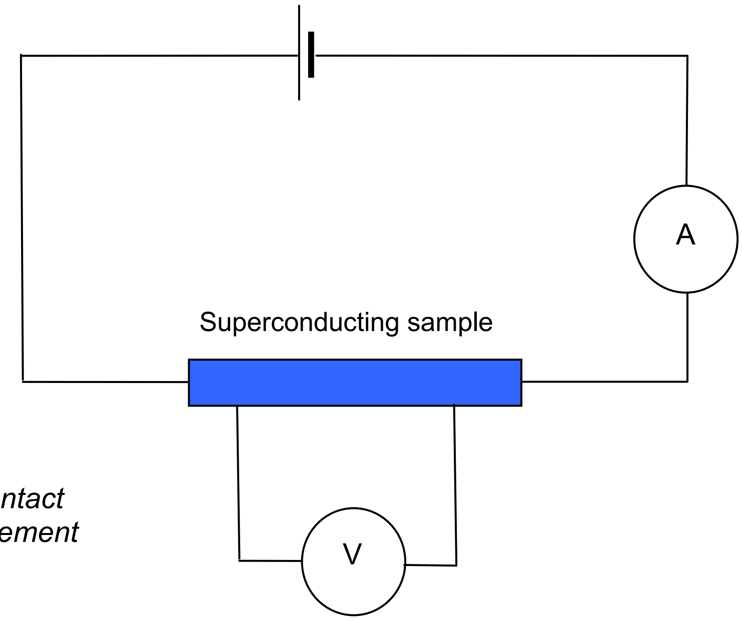


Figure 2: four point contact for resistance measurement

Since resistivity, ρ, is related to resistance, R, by: $R = \rho \frac{L}{A}$

where L and A are length and cross-sectional area respectively. Then measuring $R = 0$ when I is finite implies ρ is zero.

Measuring temperature

Given that the *stated* transition temperature of YBCO is 92K (see Annett, 2004), then we need to look towards a thermocouple for the temperature measurement. Since the thermocouple will give an output as a voltage (milli-volts in this case) an opportunity is provided for pupils to produce a calibration graph for the thermocouple. In this case, however, a data table was provided and these data were used to produce a conversion equation.

The experimental set up

Creating a four point contact can be achieved by attaching contacts directly to the superconducting sample and a similar approach can be taken with either a commercial (or home-made) thermocouple using conducting silver paint.

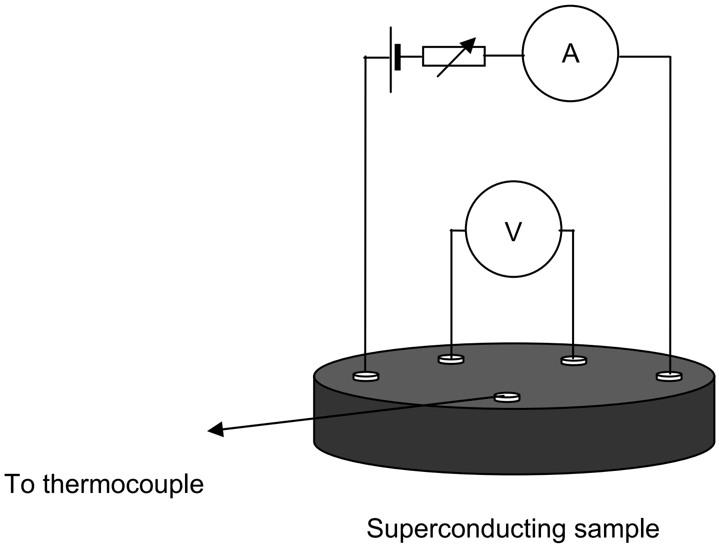
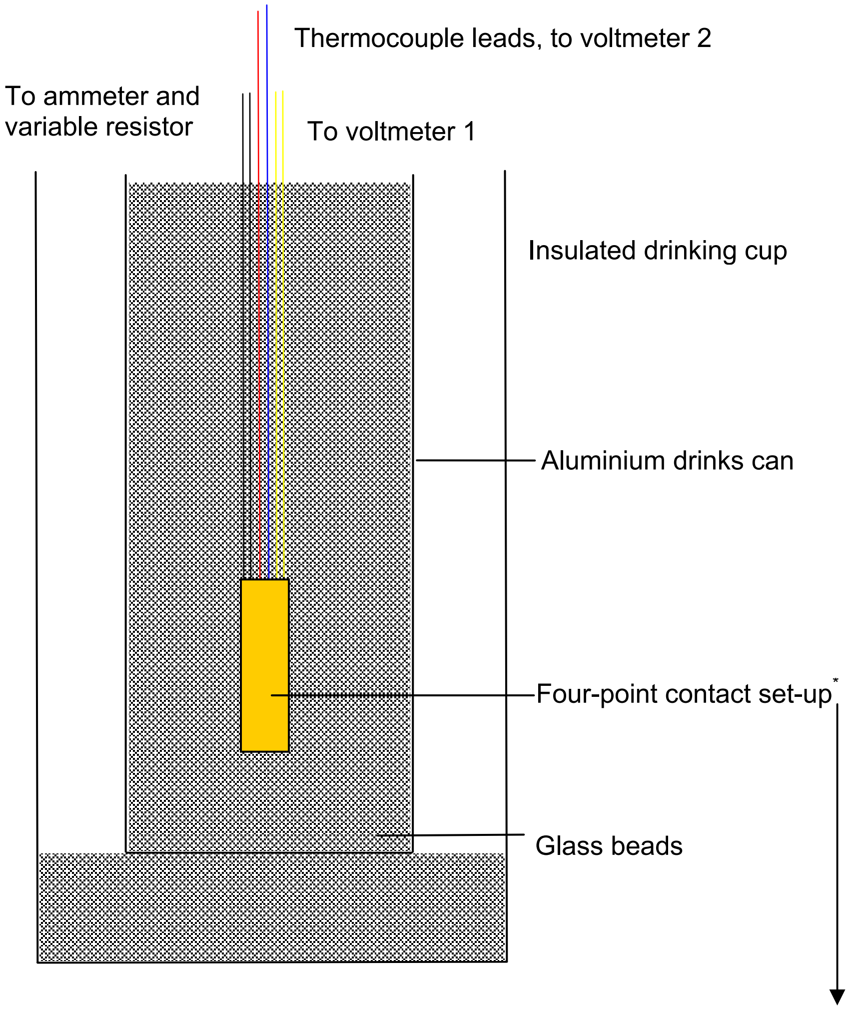
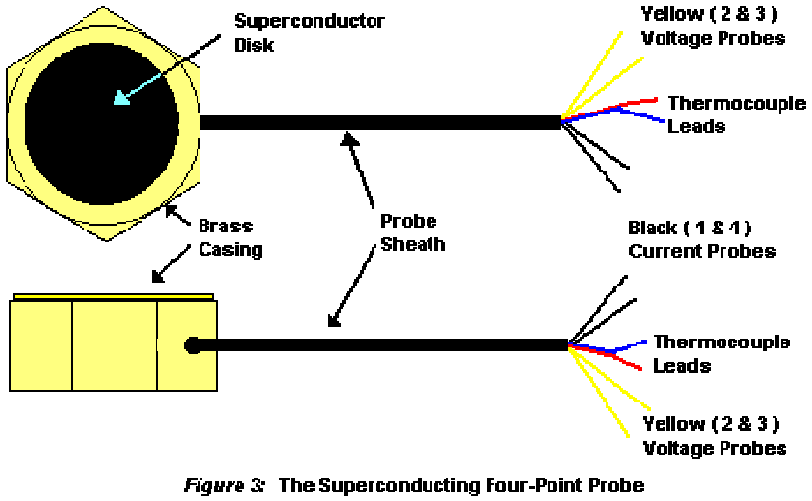


Figure 3: a four-point contact with silver paint

The SUPERCOMET 2 project intends to produce samples with the contacts ready-made for student use and what follows here uses a commercial four point contact and thermocouple unit available from Colorado Superconductors, http://www.users.qwest.net/~csconductor. Here the contacts are made directly to the sample, during manufacture and protected by a brass casing.
Figure 4 shows the set-up used to generate the results presented.





*Adapted from *http://www.users.qwest.net/~csconductor/, accessed 25.04.06*

Figure 4: the experimental set-up

Method

A variable resistor is set such that the current, through the black leads, is constant and not exceeding 0.5 A (the results obtained here used a current reading of 0.40A). Superconducting materials have a critical current, I_c, above which the resistivity will become finite and a limit of 0.5A ensures this is not the case.
The interior container is filled with liquid nitrogen until the reading on voltmeter 1 drops to zero. When a change is observed on voltmeter 1 the readings on both voltmeters are recorded and these data transferred to a suitable spreadsheet.
A simple application of V = I/R allows the resistance to be calculated from the reading on voltmeter 1 and use of the conversion data allows the reading on voltmeter 2 to generate a temperature.
Figure 5a shows the conversation data, leading to the conversion equation, for the thermocouple used and figure 5b shows the raw data collected.

Temperature/K	Voltage/mV
60	7.60
70	6.92
80	6.29
90	5.90
100	5.52
110	5.16
120	4.81
130	4.46
140	4.11
150	3.76
160	3.43
170	3.12
180	2.83
190	2.52
200	2.23
210	1.93
220	1.64
230	1.39
240	1.14
250	0.89
260	0.65
270	0.40
280	0.20
290	0.00
300	-0.20

This produces the conversion equation:

$$T = 1.77V^2 - 43.80V + 288.67$$

V1/V	Current/A	Resistance/Ω	V2/mV	Temperature/K
0.0	0.4	0.0	6.3	83.0
0.0	0.4	0.0	6.2	85.1
0.0	0.4	0.0	6.1	87.3
0.0	0.4	0.0	6.0	89.6
0.2	0.4	0.5	5.9	91.8
0.5	0.4	1.3	5.9	91.8
0.6	0.4	1.5	5.9	91.8
0.7	0.4	1.8	5.9	91.8
0.8	0.4	2.0	5.9	91.8
0.9	0.4	2.3	5.8	94.2
1.0	0.4	2.5	5.8	94.2
1.0	0.4	2.5	5.7	96.5
1.1	0.4	2.8	5.6	98.9
1.1	0.4	2.8	5.5	101.3
1.1	0.4	2.8	5.4	103.8

Figure 5a: conversion data for the thermocouple

Figure 5b: raw data collected

The glass beads provide a large thermal capacity which prevents the temperature increasing too quickly, remember some needs to read the two voltmeters.

Results

Using a simple spreadsheet allows the transition temperature to be shown on a temperature / resistance graph as shown in figure 6. The transition temperature is read as highest temperature at which R is zero.

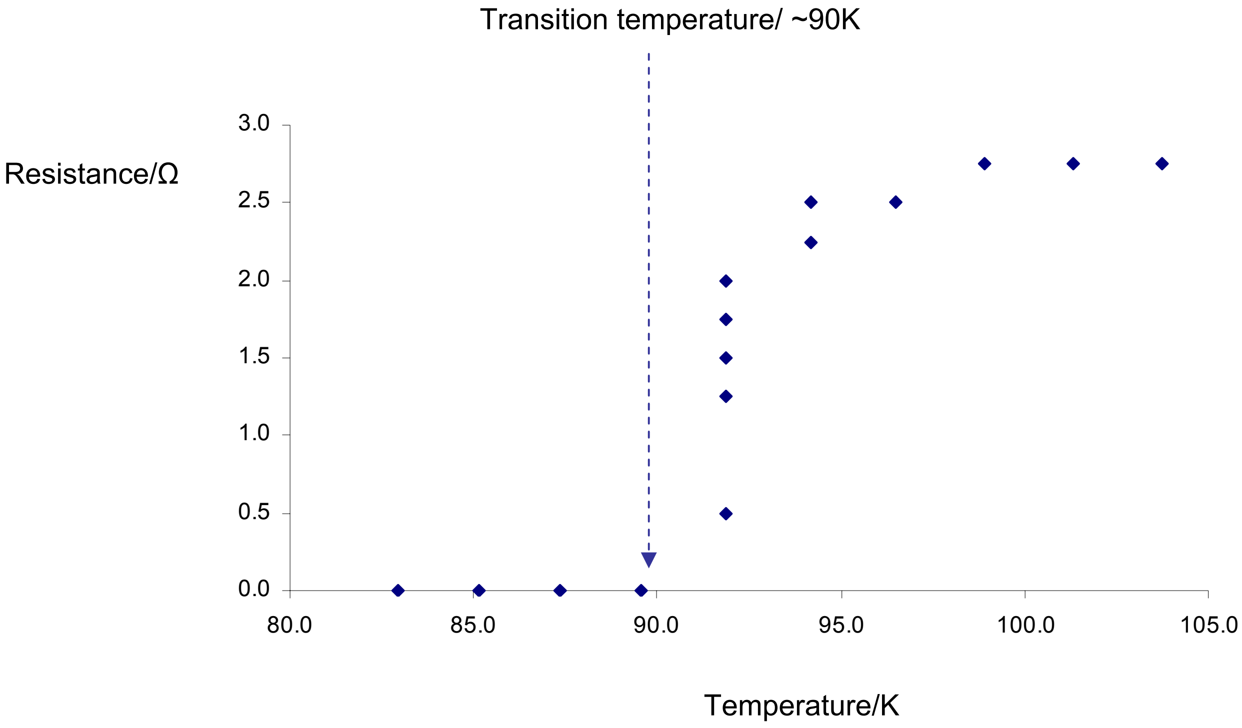


Figure 6: graph to show transition temperature

References

Annett, J. F. (2004) *Superconductivity, Superfluids and Condensates,* Oxford, Oxford University Press.

Earle, A., Frost, J., Engstrøm, V., Čepič, M., Planinšič, G., Ireson, G. and Ciapperelli, S. (2004) *SUPERCOMET Superconductivity Multimedia Educational Tool,* Trondheim, Simplicatus.

Ostermann, F and Ferreira, L M (2006) Preparing teachers to discuss superconductivity at high school level: a didactical approach, *Physics Education* **41** (1) pp 34-41

Evaluation

Basic Information

These materials are offered for you to use and adapt as appropriate for your situation. You are not expected to use all of them, just the ones that fit with your evaluation system, and to adapt them as appropriate. These materials are a compilation of materials provided by the partners[3]. All of the sheets have a space for class/teacher/pupil code numbers – these ensure that the various results can be correlated with one another should this be required. If you are not interested in doing this correlation then there is no need to put in these numbers. It is possible to use actual names, but this can cause problems with confidentiality.

Expert review of materials

If you are carrying out a review of revised materials then two approaches are presented here. The first one is the one you should normally use, and is the same as the one we used in the first round of expert reviews. Also included is a translation of a form used by our Spanish partners in Murcia[4] in their own research on hypermedia more generally because it has some interesting additional detailed questions that you may want to use in your own research.

-> Expert_review_no_1.exe (as executable program - SC Intranet)

Teachers' comments on the materials

These are materials to use if you want a fairly quick method of getting reponses from teachers:

- Suggestions for focus group questions, or for material for online discussion
- Questionnaire

Pupils' ICT background

It can be useful to know about the pupils' knowledge about ICT in order to see how this affects their use of the materials. This questionnaire should only be used when you have plenty of time with the pupils, as their comments on the materials (see next section) are more relevant for this project.

Pupils' views about the materials

Here are suggestions for a questionnaire and an interview:

- Interview
- Questionnaire

Classroom observation

More detailed information about the SUPERCOMET materials can be obtained by a series of classroom observations, the following materials provide a basis for carrying out this activity:
Three instruments are given here:

- Classroom background data – for a series of observations with the same class, this would only be completed once
- Observations of one specific lesson
- A final report and reflection of a series of lessons carried out by the same teacher

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[3] It is important to note that though some of the original instruments have been tested and evaluated, these materials have not been tried and evaluated in their present form.

[4] This and some of the other instruments used by the Murcia partners are derived from the PhD thesis 'Teaching Hypermedia Assessment' by Lucía Amorós Poveda, University of Murcia (2004).

Expert reviews: Two example studies

We present here outlines of the evaluations carried out by the groups at Udine and Murcia as a potential guide to carrying out a full evaluation.

UDINE

A. At the beginning of the study the teacher drew up a short background report on the class.

B. The teacher then produced an initial evaluation of the individual pupils (identified by a code), evaluating their (1) skills, (2) interest[5], (3) involvement, (4) socialization[6] and (5) performance. Teachers rated each item with a number between 1 and 5, according to the following definitions:

1. clearly above average
2. just above average
3. average
4. just below average
5. clearly below average

C. At the end of each session, the teacher drew up (as soon as possible after the session) a brief description of the sessions.

D. At the end of the study the teacher drew up a final report, in a free format, trying to synthesize the daily comments.

E. The teacher generated a final evaluation of each pupil using the same codes as in stage B. The scores refer to what has been done during the study.

F. At the end of the study some of the pupils were interviewed (at least three with low achievement and three with medium-high achievement) and, if possible, a collective discussion moderated by the teacher was organised. When interviewed, the pupils were allowed to look up the material gathered during the activities carried out. Before the interview pupils were asked to revise (at home or, if there is enough time, in the class) the whole work carried out.

MURCIA

The electric conduction module was used in this study. An exercise book was prepared, which pupils had to keep while they were using the SUPERCOMET materials. The teaching process lasted 5 class sessions; the learning process was as autonomous as possible, so that pupils could carry out the exercises based on observation and manipulation of the animations, and text in the materials. From time to time the teacher provided additional information that could not be extracted from the slides or he/she explained some concepts when asked by the pupils.

Several questionnaires and tools, designed for a PhD thesis “Teaching Hypermedia Assessment”, by Lucía Amorós Poveda, from University of Murcia (2004) were used. Since the instruments were already validated it was not necessary to validate the questionnaires. Data collection was carried out according to the following timetable:

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[5] Refers to physics

[6] Refers to active participation of everyday life in the classroom

MAY – 2006	INSTRUMENTS	MULTIMEDIA WORK
16, Tuesday 14:20 – 15:15	ICT attitudes and knowledge questionnaire	
17, Wednesday 14:20 – 15:15	Electric conduction pre-test	
18, Thursday 9.00 – 10.00		PUPILS WORK WITH MULTIMEDIA MATERIAL
19, Friday 11:20 – 12:15	Observation	
19, Friday 12:30 – 13:25	Observation	
23, Tuesday 14:20 – 15:15		
24, Wednesday 14:20 – 15:15		
25, Thursday 9.00 – 10.00	Electric conduction post-test	
26, Friday 11:20 – 12:15	SUPERCOMET 2 questionnaire	

Pupils in the BRG Kepler Graz, working with the SUPERCOMET application

Teachers' comments on the materials

Focus groups/on-line discussion (Teachers)

Teacher code number:

Physics:

- How important is it to introduce contemporary physics topics?
- Is superconductivity an appropriate topic to introduce in the national curriculum of physics?
- Does the use of contemporary physics topics, such as superconductivity, motivate our pupils? Does it make the learning of physics contents easier or more difficult?

SUPERCOMET materials

- How useful for physics education are the SUPERCOMET materials?
- Do the materials contain the right modules? Is the balance between topics correct?
- Is it possible to use a resource such as the SUPERCOMET e-modules in order to approach a content that isn't included in the national curriculum and yet also to cover the national curriculum?

Questionnaire (Teachers)

Teacher code number:

1. To what extent do you consider the following parts of the materials useful for your teaching?	**Not at all useful**	**A little bit useful**	**Quite useful**	**Extremely useful**	**Don't know**
Subject information (Superconductivity)					
Experiments					
Learning program					
Comment:					

2. In your opinion, how attractive and interesting are the materials for your pupils?	**Not at all attractive**	**A little bit attractive**	**Quite attractive**	**Very attractive**	**Don't know**
Subject information (Superconductivity)					
Experiments					
Learning program					
Comment:					

3. How might the materials be improved?

4. How would you use the materials in your classroom? (e.g. as preparation or as revision, for class work or for homework, display to the whole class using a data projector, or in a computer room where each pupil has access to a computer, as a replacement for the text book, or as an extra as well as the text book)

5. Problems:

- Did you notice any 'bugs' in the software? (Please give a list of any bugs noticed)
- Did you notice any mistakes in the physics content? (Please give a list of any errors noticed)
- Were there any significant difficulties in using the materials?

Pupils’ comments on the materials

Interview (Pupils)

Pupil code number:
(Interviewer: record age and sex of interviewee).

1. What have you learnt from this work on superconductivity using the SUPERCOMET materials? The answers can be organized according to:
    - concepts
    - laws and formulae
    - different ways of representation
    - ability in the lab
    - abilities connected with the use of software
2. Which sections of the course did you enjoy most? Why?
3. Which sections of the course did you enjoy least? Why?
4. What have you learnt by:
    - discussing
    - working in the lab
    - on the computer
    - studying at home
5. Let’s go through some of the work we have done. The teacher chooses a section of a topic and verifies the degree of acquisition of specific content by asking the student specific questions.

Questionnaire (Pupils)

Pupil code number:

In order to help us improve the SUPERCOMET materials, please answer the following questions:

1	Male/Female:					
2	Age: (years old)					
		Strongly disagree	Disagree	Agree somewhat	Strongly Agree	Don’t know
3	I find the subject of physics interesting					
4	I find the subject of superconductivity interesting					
5	The SUPERCOMET materials are interesting					
6	The SUPERCOMET materials stimulate my imagination					
7	The SUPERCOMET materials are easy to use					
8	The SUPERCOMET materials are attractive					
9	The SUPERCOMET materials helped me to learn					
10	The SUPERCOMET materials offer meaningful experiences					
11	The quantity of text appearing in the SUPERCOMET materials is about right					
12	The text in the SUPERCOMET materials is easy to read and understand					
13	The quantity of images appearing in the SUPERCOMET materials is about right					
14	The images in the SUPERCOMET materials					

	are clear and understandable					
15	The images in the SUPERCOMET materials explain the topic well					
16	The page design in the SUPERCOMET materials is good					
17	The movement in the animations in the SUPERCOMET materials and the speed of the screen changes are good					
18	The animations in the SUPERCOMET materials helped me to understand					
19	I found surprising things in the SUPERCOMET materials					
20	The SUPERCOMET materials promoted class discussions					
21	The SUPERCOMET materials changed my attitude about some things					
22	The experiments performed in the superconductivity course were interesting					
23	Which parts of the superconductivity course using the SUPERCOMET materials did you particularly like and find easy to use?					
24	Do you think that you have learned more through using the SUPERCOMET materials? Please give reasons for your answer.					
25	List two things that you thought were good about the SUPERCOMET materials. A B					
26	List two things that you thought were not good about the SUPERCOMET materials. A B					
27	Would you recommend the SUPERCOMET materials to the other pupils? Give reasons for your answer.					
28	What should be changed/improved about the SUPERCOMET materials?					
29	In order to use the SUPERCOMET materials do you think you needed previous knowledge in using computers? Please give reasons for your answer. In order to use the SUPERCOMET materials do you think you needed previous knowledge in science? Please state what areas you needed knowledge in: Please give reasons for your answer.					
30	Do you have any other comments about the SUPERCOMET materials:					

Thank you for your answers!

Classroom observation

Classroom background data

General

Code number:
School:
Grade:
Number of pupils enrolled:

History

Is the class involved in any other ongoing projects?
Has the class been involved in any previous projects?
What was the teaching programme in use before this study?
What physics topics were covered before the study?

Teacher

What is the level of physics education of the teacher?
What is the level of training in use of ICT or experience in use of ICT of the teacher?

Pupils

What is the average overall level of the class?
How would you describe their commitment to study?
How would you describe their achievements?
What is the level of experience of the pupils in the use of ICT?
What is the level of interest in physics?

Teaching

Use of the laboratory

Frequency (percentage of hours in the lab in total) %
Procedure:
    In small groups %
    Demonstrations from the teacher's desk %

Laboratory equipment used:

Teaching techniques

Lessons from the teacher's desk %
Discussion (free or facilitated) %
Laboratories %
Collective problem solving %
Work in small groups %
Work on the computer %
Oral tests %
Tests %
Other testing instruments (specify) %
Other (specify) %

Use of computer in class

Frequency (percentage of hours in total) %

Procedure:

In small groups	%
Demonstrations	%

Software:

Simulations (specify)	%
Programming:	%
Spreadsheet	%
Data logging	%
Use of hyper-text/multimedia (specify)	%
Development of hyper-text/multimedia	%
Other (specify)	%

Classroom lesson observation

General

Class code number:
Teacher code number:
Pupil code numbers:
Number of pupils present:
Allocated time:
Access to computers (number of PCs etc):
Date:

Goals of the lesson (topic)

Please briefly describe the goals of the lesson, topics to be covered, and the learning objectives.

Procedure

Provide a short description of the type of work carried out in the lesson (please write down the time needed for each activity when it requires more than 10 minutes).
Indicate the use of presentation, discussion, laboratory experiments, modules from the CD, and further materials (handouts, textbooks, and multimedia) provided to the pupils.

Here are three grids which may help to record what is going on in the classroom:

Computer handling							
Observation		**Appraisal of intensity of use**					
		+++	++	+	-	--	---
Pupils **ask the teacher**	About the computer						
	About multimedia						
	Other						
Pupils **ask classmates**	About the computer						
	About multimedia						
	Other						
They do not ask							

Problem solving strategies						
Observation	**Appraisal of intensity of use**					
	+++	++	+	-	--	---
They are writing (paper, pen, pencil...).						
They use the help and support material.						
They take notes.						

Class Atmosphere							
Calm	☐	☐	☐	☐	☐	☐	Tense
Individual	☐	☐	☐	☐	☐	☐	Group
Noisy	☐	☐	☐	☐	☐	☐	Quiet
Pleasant	☐	☐	☐	☐	☐	☐	Unpleasant
Good	☐	☐	☐	☐	☐	☐	Bad
Bored	☐	☐	☐	☐	☐	☐	Enjoyable

Problems

If problems occurred, then please describe them, and what action was taken to overcome them.

General Observations/Evaluation

Were the materials motivating and did they keep the pupils' attention? Which parts did they enjoy most?
Did the pupils understand the materials? Indicate any area they had particular difficulty with, or where they asked for additional explanations.
How did the pupils respond to the animations?
How satisfied were you as a teacher with the lesson? Give reasons for your answer.
Any other comments?

Classroom observation - Teacher final report

Teacher code number:

Class code number:

At the end of the study, the teacher should draw up a final report. This should be in whatever form the teacher wishes, but she/he should be asked to address the following points within her/his report:

An evaluation of the materials employed:
- Were they user friendly?
- Were they effectively understood by the pupils?
- Was the time planned for each activity appropriate?
- Was the conceptual difficulty of the materials appropriate for the level of the pupils?
- Were there any problems (please make a specific note of any problems with the use of the modules on the CD)?

Provide a synthetic and subjective evaluation, independent of the results of possible tests, on how the study has been useful both for specific purposes (for example, the understanding of electromagnetic induction) and more general ones (involvement, understanding of the use of models, development of positive attitude towards the subject etc).

If there were any difficulties, how were they solved?

Were connections established with other topics in physics or other subjects?

How did the pupils behave during the study, were they interested, keen, critical (compared to their normal behaviour outside the study); did they work well together? Were there situations during the study in which the behaviour of individual pupils has been clearly different (either in a positive or negative way) from their usual behaviour?

Please provide any other comments (either specific or general) about the materials, and make any suggestions about how they might be changed or improved.

Please, conclude by telling us briefly if you think that the work carried out has been useful, or whether you think that the costs of the project would have been better employed in a more traditional way.

Further resources

Books on Superconductivity

Annett, F. J. (2004)
Superconductivity, superfluids and condensates, Oxford, OUP

Buckel, W. and R. Kleiner (2003).
Superconductivity: fundamentals and applications. Weinheim, Wiley.

Evetts, J., Ed. (1992).
Concise Encyclopedia of Magnetic & Superconducting Materials. Advances in materials science and engineering.
Oxford, Pergamon.

Fossheim, K. and A. Sudbo (2004).
Superconductivity: Physics and Applications.
John Wiley & Sons.

Rose-Innes, A. C. and E. H. Rhoderick (1978).
Introduction to Superconductivity.
Oxford, Pergamon.

Tinkham, M. (1996).
Introduction to Superconductivity.
New York; London, Mc Graw Hill.

Vidali, G. (1993).
Superconductivity: the next revolution?
Cambridge, Cambridge University Press.

Web Resources on Superconductivity

http://superconductors.org – Superconductors.org is a non-profit, non-affiliated website intended to introduce beginners and non-technical people to the world of superconductors.

http://superconductors.org/Links.htm – This is a large set of links on super- conductivity from the same website.

http://www.ornl.gov/info/reports/m/ornlm3063r1/contents.html – A Teacher's Guide to Superconductivity for High School Students produced by Oak Ridge National Laboratory

http://www.physicscentral.com/action/2001/supcon.html – Physics Central's short introduction to superconductivity.

http://physicsweb.org/bestof/superconductivity – Best of Physics Web produced by the Institute of Physics.

physicsweb
Physics news, jobs and resources

http://hypertextbook.com/physics/modern/superconductivity – short primer on superconductivity

Physics hypertextbook

Online Superconductivity Teaching Materials

http://www.psigate.ac.uk – Physics sciences information gateway
http://www.practicalphysics.org – website for teachers to share experiments.
http://www.teachingphysics.iop.org – the Institute of Physics provides a number of useful physics teaching materials, including on superconductivity.

Superconductivity Demonstration Kits and Materials

http://www.superconductors.org/Play.htm – gives an international list of suppliers of demonstration kits, mostly in the US.

References on using ICT in Science Teaching

Barton, R., Ed. (2004). Teaching Secondary Science with ICT. Learning & Teaching with Information & Communications Technology. Maidenhead and New York, Open University Press.

Fullick, P. (2004) : Knowledge building among school students working in a networked computer supported learning environment. Southhampton 2004. **http://www.soton.ac.uk/~plf/rsch1.htm**

Osborne, J. and S. Hennessy (2003). Literature Review in Science Education and the Role of ICT: Promise, Problems and Future Directions, NESTA Futurelab.
http://www.futurelab.org.uk/resources/documents/lit_reviews/Secondary_Science_Review.pdf

http://schools.becta.org.uk Becta's one-stop shop aimed at school practitioners offe-ring a wide range of information, advice and guidance on using ICT.

http://www.leggott.ac.uk/pdfs/awards/ICTinsupport.pdf gives a good summary of using ICT to support science teaching

Newton, L. R. and Rogers, L. (2001) Teaching Science with ICT, London, Continuum

Wellington, J and Ireson, G (2007) (chapter 7) Science Learning, Science Teaching, London, Routledge

Other references used in this Teacher Guide

Institute of Physics (2004), The post-16 Initiative. Radical, forward looking initiative by the Institute of Physics, shaping and developing physics for all involved post-16.

Wellington, J. (2004). Multimedia in science teaching. Teaching Secondary Science with ICT. R. Barton. Maidenhead; New York, Open University Press.

European Commission, Directorate-General for Research, Information and Communication Unit (2007) : The Rocard Report on Science Education.
http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf