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MaNEP Newsletter

Materials with Novel Electronic Properties

Contents :

No. 2, Spring 2002

MaNEP is a National Centre of Competence in Research (NCCR) with the University of Geneva as Home Institution
The NCCR are managed by the Swiss National Science Foundation on behalf of the Federal Authorities

Message of the Director

MaNEP has now passed the first 9 months of its existence and the research activities have started to produce their first results. Ahead of us lies the challenge to develop new synergies and exploit the potential for collaborations inside MaNEP.

A first effort in this sense was the organisation of the « Swiss Workshop on Materials with Novel Electronic Properties » at Les Diablerets on October 1-3, 2001. This meeting attracted 160 participants and allowed a broad discussion of some of the main topics of MaNEP.

Further efforts to enhance synergies and collaborations are under way. The Newsletter is one of these. It has the role to inform about research and events related to MaNEP. For this issue and the following ones, we shall each time present some of the groups working within MaNEP. We furthermore plan to have a scientific article by one of the MaNEP members and, associated to this, a brief presentation of the topic to a broader public.

In this issue, we focus on the use of muons in the field of novel materials. This allows also to illustrate one of the important research tools available at the Paul Scherrer Institute in Villigen. Finally, the Newsletter shall continue to have short research news from inside and outside MaNEP, as well as information about coming events.

The MaNEP adventure has just begun, but it is my hope that you can already feel the enthusiam of the people in our NCCR through reading our newsletter.

Øystein Fischer

MaNEP Management Team

MaNEP is a constellation in which gravitate about 200 scientists spread all over Switzerland into 8 public institutions and 3 companies. Managing this broad network and supporting the research teams to reach the challenging objectives of this National Centre of Competence in Research (NCCR) is a fulfilling task.

From left to right: Mrs I. Bretton, Dr. A.A. Manuel, Mrs. H. Segura, Prof. J.-M. Triscone, Prof. Ø. Fischer, Dr. M. Kugler, Dr. O. Kuffer, Dr. M. Decroux, and Dr. I. Maggio-Aprile.

MaNEPs Leading House is based at the University of Geneva, where a dynamic team of motivated people is managing the network under the guidance of the NCCR director, Prof. Ø. Fischer and the deputy director Prof. J.-M. Triscone.

Budgeting and accounting are activities which are vital for the operation of MaNEP. They are managed by Mrs. Isabelle Bretton, whereas Dr. M. Decroux, Scientific Manager, takes care of the necessary administrative tools.

An objective of MaNEP being to prepare future generations of scientists to excel in the field of novel electronic materials, Dr. M. Decroux has also the important assignment to organize training and education in this field.

To be effective, a network needs by definition a sustained flow of information and well-targeted communication.

Meetings and conferences, organized under the lead of Prof. J.-M. Triscone and the publication of internal research reports, edited by Dr. A. A. Manuel, Scientific Manager, are key ingredients for successful scientific networking.

MaNEP's website is another essential communication tool which is managed by Dr. Ivan Maggio-Aprile.

The application potential of the materials studied within MaNEP is spectacular. To reach the industry sector, knowledge and technology transfer plays an important role.

Dr. O. Kuffer and Dr. M. Kugler have the responsibility to open the dialog with Swiss industry and to create opportunities for new collaborations.

On top of these exciting challenges, MaNEP seeks visibility and targets the interest of a large public. The edition and large diffusion of the biannual Newsletter is tackled by Dr. O. Kuffer, Dr. M. Kugler, Dr. A. A. Manuel and Dr. I. Maggio-Aprile.

Finally, all these activities wouldn't be effective without Mrs. Heidi Segura who takes care of all secretarial duties.

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Muons as Microscopic Probes in Condensed Matter

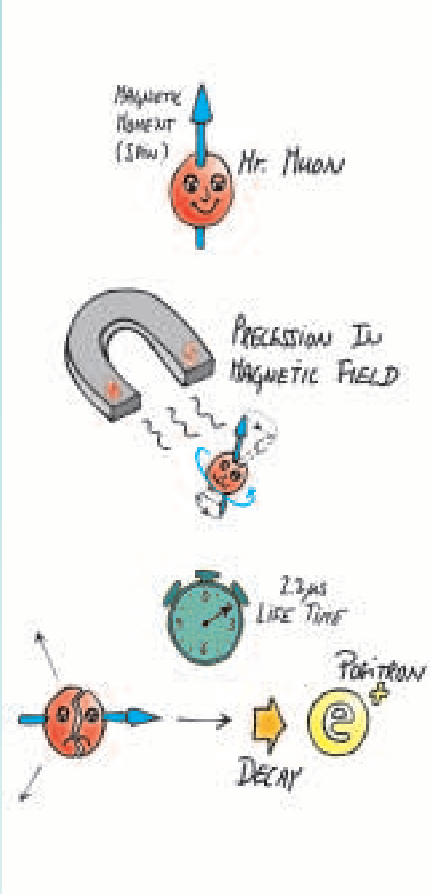
What is a Muon?

A positive muon μ^+ is a fundamental particle which has a positive charge and is about 200 times heavier than an electron. It has a magnetic moment, and therefore muons can be considered as little magnetic gyroscopes which precess in magnetic fields. The muon has a finite life time of 2.2 μs and decays into a positron e^+ and two neutrinos. Due to parity violation the positron is emitted preferentially along the direction of the magnetic moment of the muon. From the measurement of the number of decay positrons as a function of time after a muon has stopped in a sample, the local magnetic field experienced by the muon can be extracted. This technique is known as muon-spin rotation (μSR) spectroscopy.

Why using Muons?

Implanted into a material, muons can probe the internal, local magnetic field, and with low-energy muons even on a nanometer scale. Therefore the technique is very useful for studying magnetic compounds and superconductors, as shown in the scientific article of this Newsletter.

In other experiments, muons can be used to provide information on the properties of hydrogen in materials or to probe structural defects in crystals.



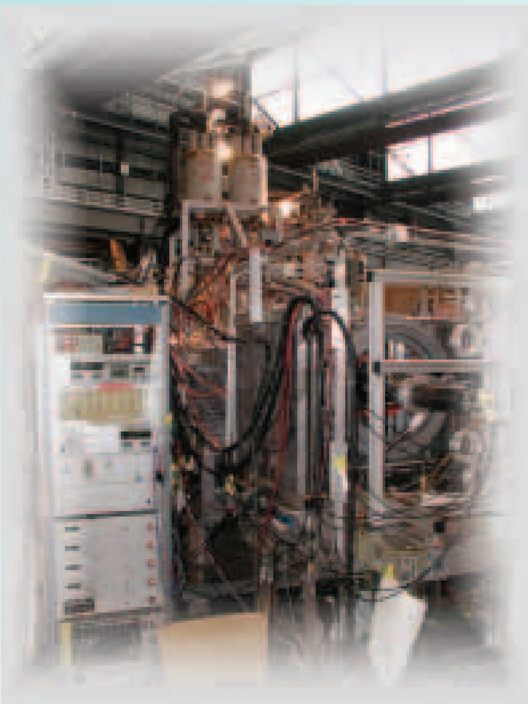
How to produce Muons?

A muon beam can be produced by hitting a graphite target with a proton beam accelerated to 80% of the speed of light. Muons are obtained as decay products of pions produced in such collisions.

Such beams are available in Switzerland at the Paul Scherrer Institute (PSI) in Villigen.

Unique Muon Facilities at the Paul Scherrer Institute

The muon facilities at PSI allow a wide spectrum of experiments attracting solid-state physicists, chemists and materials scientists from all over the world.



Muons are universally applicable microscopic magnetic probes that can be implanted into a large variety of materials and under many different external conditions. The measurable magnetic fields using muons range from only one tenth to a hundred thousand times the magnetic field of the earth with characteristic times from nano- to milliseconds. This turns then into a powerful tool to investigate fundamental and technologically relevant aspects of structural, magnetic and electronic phenomena in magnetic compounds, such as superconductors, semiconductors or insulators. These materials further range from pure elements to complex alloys like organic compounds or molecular systems with manifold structures (crystalline, amorphous, liquid, etc.). The experimental versatility is extended by the possibility to perform muon studies at variable temperature, pressure, or electromagnetic fields.

For more information on muon spectroscopy, visit http://lmu.web.psi.ch/

Six different instruments are available for research using the muon beams at PSI. Among them, two very special facilities that are worldwide unique:

- A **Low Energy Muon Beam** allowing to implant muons at very small and controllable depths (down to a few nanometers) below the surface of a sample, thus making a wealth of new applications available by extending the studies to very thin samples, multilayered structures and surface regions, and by measuring material properties as a function of the implantation depth on a nanometer scale (see scientific article).

- **The extraction of one muon at a time from a continuous beam – Muons on Request, "MORE"** – provides unique sensitivity to small magnetic field differences and extends the measurable characteristic times into the milliseconds range at the full timing resolution.

Superconductors for High-Current Applications

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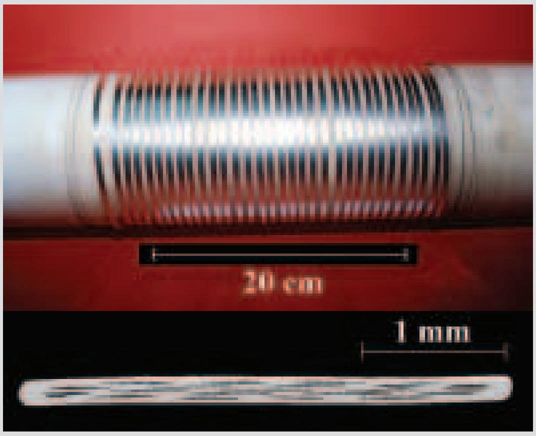
The interest of the group is directed to material science for applications, with a special regard to superconducting materials. The research activities include crystal growth, high-pressure synthesis and thermodynamics, as well as the study and fabrication of superconducting wires and tapes and the deposition of superconducting thick films on textured Ag.

The superconducting materials of interest are both low-T_c and high-T_c compounds, namely Nb_3Sn, Nb_3Al, MgB_2, $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10-x}$/Ag (Bi2223/Ag) and $YBa_2Cu_3O_{7-x}$. The study of the superconducting properties of these compounds and devices is performed in magnetic fields up to 17 Tesla. Critical temperature, critical current, transport properties as a function of temperature, field and strain, DC magnetisation and AC magnetic susceptibility are measured in our laboratories.

The main activities carried out under MaNEP are the development of both low- and high-T_c superconducting materials for high-current application: Nb_3Sn, Nb_3Al, MgB_2 and Bi2223. For the first two compounds investigations focus on the processing technique and the increase of the superconducting critical current at high magnetic fields. For the last two compounds our studies include thermodynamics, bulk sintering, tape and wire fabrication and high pressure synthesis.



Ag sheathed Bi2223 multifilamentary tape

References:

[1] H.L. Suo et al., Appl. Phys. Lett. **79** (2001), 3116.
[2] E. Giannini et al., Studies of High-Tc Superconductors, vol. **36** (2001) , 1, edited by A. Narlikar, Nova Science.

Superconductor-Insulator Transition of Underdoped Cuprates

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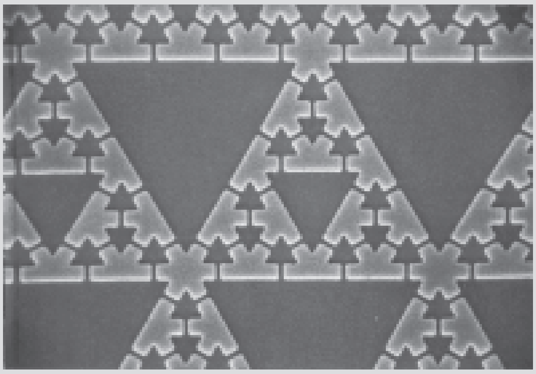
The heart of investigations carried out at the University of Neuchâtel are classical and quantum ordering phenomena in low-dimensional superconductors. In this context collective and topological excitations as well as disorder, frustration and localization effects play an essential role.



Array of SNS Josephson junctions [S=Pb (clear), N=Cu (dark)] with the geometry of periodically repeated Sierpinski gaskets.

To gain insight into these complex phenomena, we rely on Josephson junction arrays prepared with modern nanofabrication techniques. When studied with very sensitive SQUID-based methods, these model systems provide a unique testing ground to explore in great detail and with high accuracy theoretical predictions emerging from fundamental concepts of condensed matter physics and statistical mechanics. These investigations prove to be very useful to link the physics of the arrays to that of high-temperature superconductors, in particular to the magnetic and critical properties of thin films, another central topic of our experimental activity.

On the theoretical side we aim at understanding the unexpected features observed in the dynamic response of arrays and thin films in the critical region and, within the framework of microscopic models, the existence of a pseudogap above the superconducting transition. The group has established a long standing collaboration with the DPMC of the University of Geneva and the IBM Research Laboratory.

References:

[1] M. Calame et al., Phys. Rev. Lett. **86** (2001), 630.
[2] P. Curty and H. Beck, Phys. Rev. Lett. **85** (2000), 796.

Electronic Transport in Novel Materials

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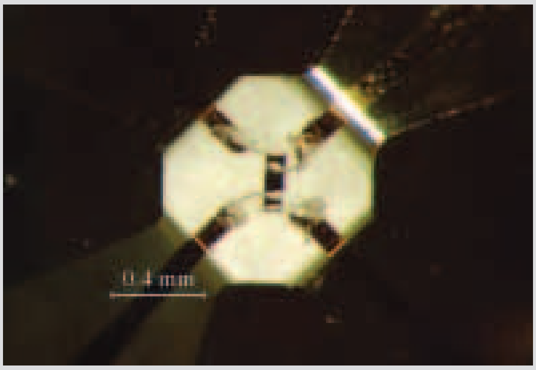
The Research Group on Nanostructures and Materials with Novel Electronic Properties of László Forró, conducts experiments in condensed matter physics in the Institute of Physics of Complex Matter of the Faculty of Basics Sciences at the Ecole Polytechnique Fédérale de Lausanne . The major classes of materials investigated are (i) Novel electronic materials (cuprates, manganates, vanadates), (ii) Molecular materials (fullerenes, carbon and non-carbon nanotubes) and (iii) Biological nanostructures (microtubules, DNA).

We are interested in the electronic, magnetic, structural and mechanical properties of these systems. The primary goal is to explore and understand the rich underlying physics. A variety of experimental techniques are used to characterize these materials. The characterization includes both well-established methods such as general transport (electrical conductivity, thermopower, magnetotransport, Hall effect), high pressure transport, optical spectroscopy, tunneling spectroscopy, AFM, TEM/SEM, and novel techniques developed in the laboratory, like electron spin resonance (ESR) at high pressures and in stopped-flow configuration.



A cuprate superconductor single crystal mounted on a diamond anvil with sputtered gold electrodes for high pressure transport measurements.

In the MaNEP project "Electronic transport in novel materials" the major themes are: interlayer transport in layered materials like cuprate superconductors or bilayered manganates, Mott-transition and non-Fermi liquid behavior in $BaVS_3$, and the role of correlations in carbon nanotubes.

References:
[1] L. Forró et al., Phys. Rev. Lett. **85** (2000), 1938.
[2] B. Ruzicka et al., Phys. Rev. Lett. **86** (2001), 4136.

Theoretical Modelling of Materials with Novel Electronic Properties

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This project combines three groups of theorists, led by Dionys Baeriswyl (University of Fribourg - http://www.unifr.ch/phystheo), Frederic Mila (University of Lausanne - http://www-sphys.unil.ch/ipt) and Maurice Rice and Manfred Sigrist (ETH Zürich) with the goal of developing a deeper understanding of novel physical phenomena and effects in materials of interest. Where possible, we strive for a close collaboration and engagement with experiment, since successful interchange between theory and experiment is the key to success in this field.

The activities are spread over several projects covering a number of materials. The main themes are drawn from the fields of unconventional superconductivity, metal-insulator transitions and quantum magnetism. In all cases there are strong interactions between the electrons and their motion is strongly correlated, which poses a challenge to theory. Numerical simulations are an important tool to supplement analytic methods.

References:
[1] F. Mila et al., Phys. Rev. Lett. **85** (2000), 1714.
[2] M. Zhitomirsky and T.M. Rice, Phys. Rev. Lett. **87** (2001), 057001.

Probing Microscopic Magnetic Properties of High-Temperature Superconductors with Muons

Hugo Keller, Physik-Institut, Universität Zürich, Switzerland
Elvezio Morenzoni, Paul Scherrer Institut (PSI), Villigen, Switzerland

Research Group

The group of Prof. Dr. H. Keller has a strong expertise in investigations of magnetic and thermal properties, and oxygen-isotope effects of high-temperature superconductors and related materials. Various complementary experimental techniques such as, SQUID and torque magnetometry, resistivity and specific heat measurements, as well as resonance techniques (NMR/NQR, EPR, µSR) are applied to investigate the same physical problems. The novel low-energy µSR method recently developed by PD Dr. E. Morenzoni and coworkers at PSI is a new very powerful tool in the research field of the group.

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The muon-spin rotation (µSR) technique has demonstrated to be a unique and powerful *microscopic* probe to investigate local magnetic fields in high-temperature superconductors (HTSC). Recently, a novel low-energy (LE) µSR method was developed at the Paul Scherrer Institute (PSI) which allows to explore local magnetic field profiles in HTSC near the surface of thin films and multilayer structures.

Bulk µSR technique

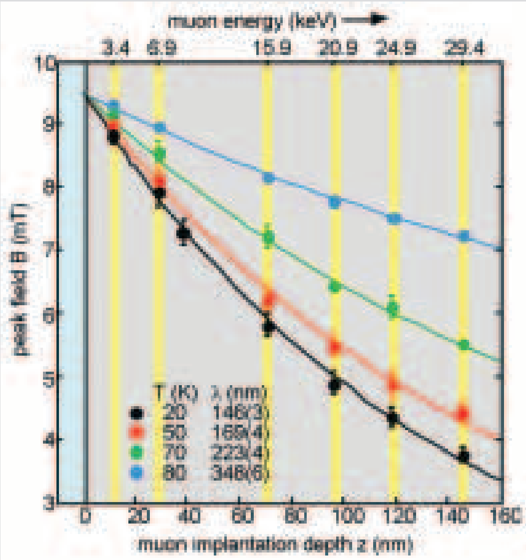
In a µSR experiment spin-polarized positive muons μ^+ serve as a *microscopic* magnetic probe of the local magnetic field distribution in the bulk of HTSC. In many cases µSR has provided important information on the complex vortex structure in HTSC, which is hardly obtained with other experimental techniques. Over recent years a collaboration between the Universities of Zurich, Birmingham, and St. Andrews has played a major role in applying µSR to many aspects of vortex physics in HTSC and other unconventional superconductors. Highlights of this work include the first microscopic observation of flux-lattice melting and disorder crossover in the highly anisotropic HTSC $Bi_2Sr_2CaCu_2O_{8+\delta}$ [1] and the microscopic observation of the suppression of vortex fluctuations in $Bi_2Sr_2CaCu_2O_{8+\delta}$ containing columnar defects [2], to give only two examples.

Low-energy µSR technique

So far µSR studies have been performed using μ^+ with energies of about 4 MeV, which require rather thick (≈1mm) samples. Recently, Morenzoni *et al.* [3] have developed a low-energy (LE) beam of spin-polarized μ^+ at PSI. Very slow muons with kinetic energy of about 10 eV are obtained from the moderation of high-energy μ^+ with an initial energy of about 4 MeV in a thin film of a condensed gas. These slow μ^+ of tunable energy between 0 eV and 30 keV can be implanted at very small and controllable depth below the surface of a sample. This allows to exploit all the advantages of bulk µSR in studies of local magnetic fields in thin samples, near surfaces, and as a function of depth below surfaces. The spectrum of possible applications of LE-µSR is broad, including superconducting thin films, magnetic/superconducting and normal-conducting/superconducting multilayers, nanostructured materials, and quasi two-dimensional magnetic systems.

Recent result

So far, the most beautiful demonstration of the power of LE-µSR is the first direct observation of the spatial variation of the magnetic field (magnetic flux penetration) beneath the surface of a superconductor in the Meissner state [4]. This was achieved by applying a magnetic field parallel to the CuO_2 planes of a c-axis oriented, 700 nm thick epitaxial $YBa_2Cu_3O_{7-\delta}$ film and then measuring the field profile inside the superconductor by implanting LE muons at various depths (~ 15 to 150 nm). The observed field profile is in excellent accordance with that expected for a thin film from London theory (see Figure).



Magnetic field profile B(z) in a 700nm thick c-axis oriented $YBa_2Cu_3O_{7-\delta}$ film in the Meissner state near the surface, measured in an external field of B_0 = 9.5 mT at various temperatures [4]. Using the London theory expression, the experimental data were fitted (solid lines) allowing to deduce a London penetration depth of 146±3 nm at 20K, in agreement with other experiments.

Outlook

Due to their layered structure and unusual electronic properties HTSC give rise to a much more exotic vortex structure than found in conventional superconductors. While HTSC have many potential applications, their usefulness depends crucially on the properties of the vortex state. A detailed understanding of these properties is thus relevant to applied superconductivity. A more fundamental interest of the physics of HTSC is in the exciting field of vortex matter. HTSC represent ideal model systems for the study of wider aspects of vortex matter. The unique advantage of LE-µSR is its ability to extend µSR studies of local magnetic fields in HTSC to thin films and various kinds of multilayer structures. This opens a completely new domain in vortex matter physics research. At present PSI is the only place in the world where LE-µSR experiments can be performed.

References

[1] S.L. Lee *et al.*, Phys. Rev. Lett. **71** (1993), 3862.
[2] S.L. Lee *et al.*, Phys. Rev. Lett. **81** (1998), 5209.
[3] E. Morenzoni *et al.*, J. Appl. Phys. **81** (1997), 3340.
[4] T.J. Jackson *et al.*, Phys. Rev. Lett. **84** (2000), 4958.

A basic introduction on muons is given at the beginning of the Newsletter.

Recent Highlights - World

TOWARDS MAGNETIC REFRIGERATORS ?

Nowadays, refrigerators extract heat using a mechanical compressor and chlorofluorocarbons, an environmentally damaging class of chemicals. Magnetic refrigeration might soon be an alternative, offering a better efficiency and no risk of atmospheric pollution.

A team of researchers from the Netherlands [1] has found a magnetic compound, predominantly made of iron and manganese, that could act as refrigerant at room temperature. The idea, based on the second principle of the thermodynamics, is rather simple to understand: Applying a magnetic field to the randomly oriented magnetic moments of the material will produce heat when the magnetic moments align. Let us transfer the heat to the surroundings and then remove the magnetic field. The magnetic moments randomize again and the material is cooled down below the ambient temperature. That's it ! Using a heat-transfer medium like water with antifreeze it would be rather simple to construct the noiseless, efficient, and environmentally friendly fridge of tomorrow. What is new? The material. It has a Curie temperature of about 300 K, a large magnetocaloric effect (MCE) and requires moderate external magnetic fields to perform the thermodynamic cycle. The compound discovered by O. Tegus and collaborators is the first to exhibit a giant-MCE at room temperature. Its low cost makes it an attractive candidate for a commercial magnetic refrigerator. The future will tell us if this technique will have an impact on tomorrow's household fridges.

Reference:

[1] O. Tegus et al. *Nature* **415** (2002),150.

SUPERCONDUCTIVITY : THE MAGNETIC TRAIL

The mechanism hidden behind high temperature superconductivity is still a fascinating mystery that challenges a large community of physicists. One important slow down in the quest for "the" solution is the apparent non uniformity in the behavior of superconducting compounds regarding various properties. However, recently a unified explanation has been proposed for the very unusual magnetic properties.

A team of researchers from Germany, France and Russia claims to have made an substantial advance in the characterization of a uniform magnetic excitation by neutron scattering [1,2]. The high temperature cuprate superconductors are made of copper oxide layers separated by metal atoms. The super-current flows in these layers, whose number vary from a compound to the other. Previous neutron scattering studies had pointed out that, in bi-layers and tri-layers compounds, the electrons in the copper oxide layers are excited in a magnetic resonant mode. But, until now, this highly peculiar electronic state was notably absent in single-layer compounds. It has been now observed in $Tl_2Ba_2CuO_{6+\delta}$, a single-layer compound. This unusual spin excitation mode has inspired numerous theoretical studies, but the lack of consistency in the experimental observations has refrained their potential validity until now. This new result "highlights the central role of magnetism in the mechanism of high-temperature superconductivity" declares B. Keimer, the leader of the team [3]. "The first observation of the so-called magnetic resonance peak in a single-layer high-T_c system may turn out to be a breakthrough towards a unified phenomenology of the cuprates, provided that this outstanding result can be confirmed by another group for another single-layer compound", says A. Furrer MaNEP project leader from PSI & ETH Zürich.

Reference:

[1] H. He et al, Science **295** (2002), 1045.
[2] H. He et al. SciencExpress 110.1126/science.1067877, 24 January 2002.
[3] PhysicsWeb, 24 January 2002.

CHEAPER TRANSFORMERS IN SIGHT

The running cost of electric transformers made of magnesium diboride (MgB_2), the most recently discovered superconductor, is estimated to be 35% lower than the one of standard Cu-based transformers, and 50% lower than devices made of copper oxides, an other class of superconducting materials [1].

What makes superconductors attractive is the large decrease of energy losses they offer. While these losses represent 90% of the operation costs of the resistive transformers, they amount to only 10% for the superconducting one. Among the superconducting transformers, the cheap production costs of the MgB_2 wires is attractive, even if cooling expenses are higher, as it superconducts only below a temperature of 39 K, while the limit is above 77 K for copper oxides, allowing the use of a cheaper coolant: the liquid nitrogen. Shall we conclude that the road for magnesium diborides is straight and promising? The challenge for MgB_2 wiremakers is to improve the ability to carry super-currents. Laboratory experiments suggest that MgB_2 might soon meet the industrial demands, but today copper oxide tapes have still higher critical currents and better characteristics under magnetic fields. "Although there is no doubt about the potential of MgB_2 wires for industrial applications, the cooling costs for long operating durations, such as needed in transformers, will remain the limiting factor", says R. Flükiger MaNEP project leader from University of Geneva.

Reference:

[1] R.F. Service. *Science* **295** (2002), 786.

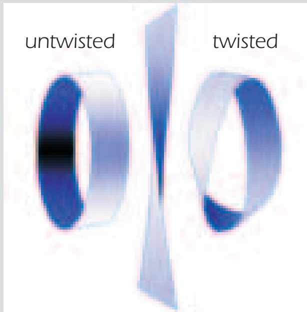
Recent Highlight - MaNEP

TOPOLOGY FOR QUANTUM COMPUTING

Quantum computers will solve tasks which are beyond the computational capabilities of today's classical machines. The main challenge is to build new physical units – quantum bits or *qubits* - that carry the information in the quantum computer without loosing coherence. But how do you build a device which you want to manipulate without perturbing it ?

Many qubit designs have been proposed, but the ultimate goal of reaching coherent evolution over thousands of elementary operations is still a formidable task. Kitaev [1] had the brilliant idea of protecting qubits from decoherence by exploiting topological stability, but so far, its physical implementation remained unsolved. A new proposal [2] has been made by a MaNEP team from ETH Zürich in collaboration with Rutgers University and the Landau Institute. They identified a strongly correlated many-body system having all the physical properties necessary for the construction of a topological qubit. They propose to realize this system using a Josephson junction array with properly tuned couplings and gate electrodes.

How does topology help to maintain coherence? The answer can be illustrated with the help of the Möbius strip. The two qubit states correspond to the configurations of the strip, untwisted and twisted. While these states are topologically different, they are indiscernible through local inspection. Translated to the qubit this implies that no local perturbation or measurement can distinguish the two states and that any such perturbation will affect the states in the same way. This stability towards local perturbations renders the device robust against fabrication errors and decoherence. Although the complexity of this architecture challenges today's technology, quantum computing should greatly benefit from such fault-tolerant qubits.



The two states of a topological qubit can be understood as a strip that can be rolled up into two topologically different configurations - untwisted and twisted - which are not distinct through local inspection alone.

References:

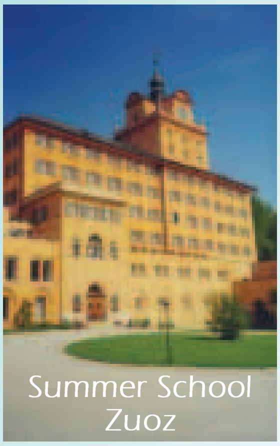
[1] A.Yu. Kitaev, quant-ph/9707021.
[2] L.B. Ioffe, M.V. Feigel'man, A. Ioselevich, D. Ivanov, M. Troyer, and G. Blatter, Nature **415** (2002), 503.

Events

1st PSI Summer School on Condensed Matter Research, Zuoz, GR, August 10-17, 2002.

MaNEP is associated to the Paul Scherrer Institute which organises a Summer School with the objective to give an introduction to the basic principles of magnetism and magnetic materials.

The lectures will cover both, theoretical and experimental aspects, with particular emphasis on the utilization of the prominent experimental techniques available at PSI: neutrons, muons, and synchrotron light. The registration deadline is **June 30, 2002**. For more information and on-line registration, consult:
http://psw100.psi.ch/www_sls_hn/zuoz_cmr2002



MaNEP Inauguration Day

MaNEP leading house will open its doors in September 2002 and exciting experimental demonstrations will be performed.
The event will take place at the physics department, University of Geneva, 24 Quai Ernest-Ansermet.
An official afternoon will also be jointly organised.
All details will be available soon on the MaNEP website:
http://www.manep.ch

MaNEP Newsletter
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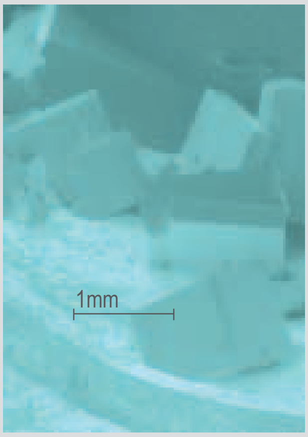
Cover Picture



Electron Microscope image of high purity superconducting single crystals of $YBa_2Cu_3O_7$ grown in $BaZrO_3$ crucibles.

A. Erb, E. Walker, R. Flükiger., University of Geneva, Switzerland.

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