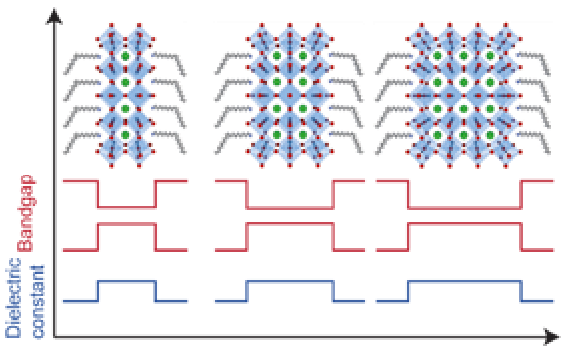
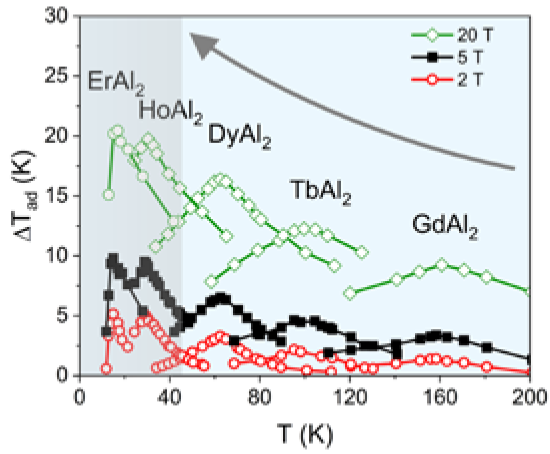
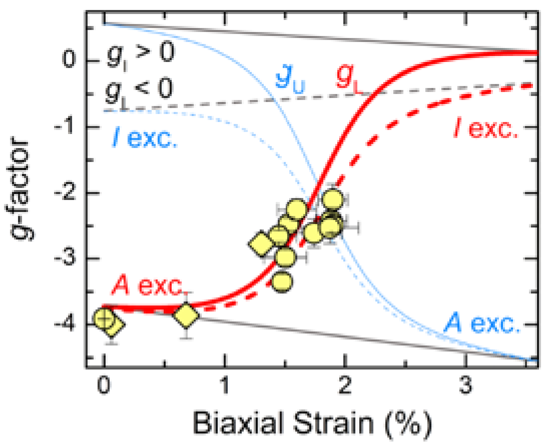
European Magnetic Field Laboratory

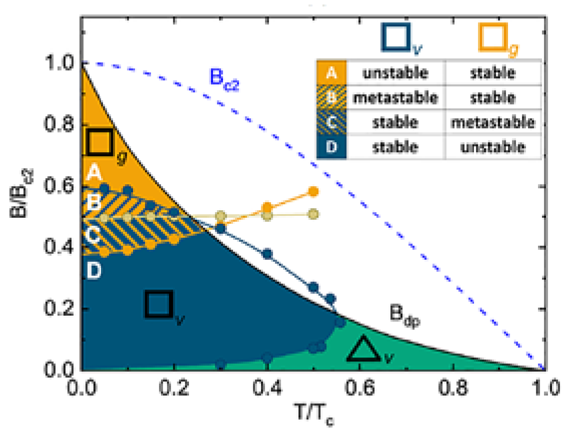
EMFLNEWS

N°3 2022









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DEAR READER

The new call for proposals has been opened (deadline November 15) and this call marks the launch of several new access modes. First of all, we started a fast-track access mode, which is permanently open, and which permits to request the EMFL Board of Directors (BoD) to grant magnet time for a project with a convincingly urgent scientific case. The second new access mode is a technical-development access, dedicated to the interest of scientists wishing to develop and improve technical installations and metrological procedures that could also be of great interest to other EMFL users. And finally, we launched a long-term access mode in order to meet the demand for schemes such as complex high-level science cases, which require a sequel of high-field experiments. More information for all calls you can find on our website.

Also in this issue of the EMFL Newsletter: the usual scientific highlights, the presentation of our regional partner, the National Institute of Chemical Physics and Biophysics (NICPB/KBFI) in Tallinn, Estonia and an introduction to one of our industrial partners, VONK in the Netherlands. Finally, this newsletter also contains a brief report of the very successful EMFL Days in Kerkrade, the Netherlands, during which the administrative, technical, and scientific staff of all EMFL facilities came together to strengthen the mutual interactions and collaborations and to discuss how to further improve our service to our user community.

Peter Christianen
Director HFML
Chairman EMFL

MEET OUR PEOPLE

Steffen Krämer, LNCMI Grenoble

Originating from the south of Germany, I'm now working and living in Grenoble for almost 20 years. I started my career at the University of Stuttgart, where I studied high-temperature superconductors during my PhD. Then, I joined two consecutive European research collaborations developing high-field NMR instrumentation and methods, which brought me in contact with the Grenoble high magnetic field laboratory, and I decided to move to Grenoble. During that time, I had the chance to work at the HFML Nijmegen, later a founding member of the EMFL, and the KBFI in Tallinn, now an EMFL partner facility.

The challenging field of NMR in high magnetic fields, often combined with very low temperatures, motivated me to join the NMR team in Grenoble as a permanent CNRS research engineer. Since that time, I'm constantly discovering interesting projects covering many scientific areas in chemistry and physics. Recent examples are studies of contrast agents for magnetic resonance imaging and strongly correlated electron systems, like high-temperature superconductors, quantum magnetism, and heavy-fermion systems.

Moreover, I'm also responsible for the instrumentation team at Grenoble. The engineers and technicians of our team develop original instrumentation and methods for many high-field experiments including advanced experimental techniques for optics, field and temperature metrology, and sample environments like dilution refrigerators.

In addition to the stimulating work in an international research facility, I enjoy the exchange and discussions with the colleagues in Grenoble, the staff at the EMFL facilities, and the users from all over the world. Over the years, some of them became friends.

In my free time, I'm hiking in the mountains around Grenoble and I'm singing in two choirs performing classical music.

For the future, I'm looking forward to the operation of hybrid and all-superconducting high-field magnets at the EMFL that should allow higher fields, new experimental techniques, as well as an energy efficient and sustainable method for the generation of high magnetic fields.

› Steffen Krämer

EVIDENCE FOR A SQUARE-SQUARE VORTEX-LATTICE TRANSITION IN A HIGH-T_c CUPRATE SUPERCONDUCTOR

J. Chang, Zürich University, M. Ichioka, Okayama University, D. Campbell, D. Le Boeuf, LNCMI Grenoble

In the physics of correlated electron systems, van Hove singularities play a key role. These are points in the band structure where the density of states is singular. When the Fermi level is tuned towards a van Hove singularity, new and exotic physics is expected, particularly in low-dimensional systems.

In two-dimensional d-wave superconductors, the presence of a van Hove singularity produces unconventional vortex-lattice phases and vortex transitions. These issues have been studied theoretically and an exotic vortex-lattice transition, occurring close to the upper critical field, has been predicted by Nakai and collaborators two decades ago (Phys. Rev. Lett. 89 237004 (2002)). Indeed, using Eilenberger's theory of the vortex lattice, they predicted that the competition between the four-fold symmetry of the d-wave superconducting order parameter and that of the Fermi velocity produced by the van Hove singularity would result in a rotation of the square vortex lattice. However, after two decades their prediction was still lacking an experimental confirmation.

The best current prospect material to observe such a transition is the high-T_c cuprate superconductor $La_{2-x}Sr_xCuO_4$ (LSCO) close to its doping-induced Lifshitz transition. However, this is a challenging task experimentally, as techniques traditionally used to study the vortex lattice are not appropriate in that case. The magnetic fields required to observe the vortex transition are far beyond the capabilities of small-angle neutron scattering and scanning tunneling microscopy is not applicable to LSCO as high-quality surfaces are not realized in this compound.

In this work, researchers at LNCMI, in collaboration with Zürich University (Switzerland), Hokkaido University (Japan), and Okayama University (Japan), use a new approach to test this prediction with ultrasound measurements up to 60 T. Ultrasound is sensitive to the elasticity and pinning of the vortex lattice, both of which are affected by such kind of transition.

They found a new transition in the compression modulus of the vortex lattice of LSCO, observed in magnetic fields exceeding 35 T, deep within the mixed state. The transition is only observed within the pinned vortex-solid phase indicating it is related to a structural transformation of the vortex-solid. Theoretical analysis, based on Eilenberger's theory of the vortex lattice using tight-binding parameters specific to LSCO with x = 0.17 support the interpretation of the discovered ultrasound anomaly in terms of the square-square vortex-lattice transformation predicted by Nakai and co-workers 20 years ago.

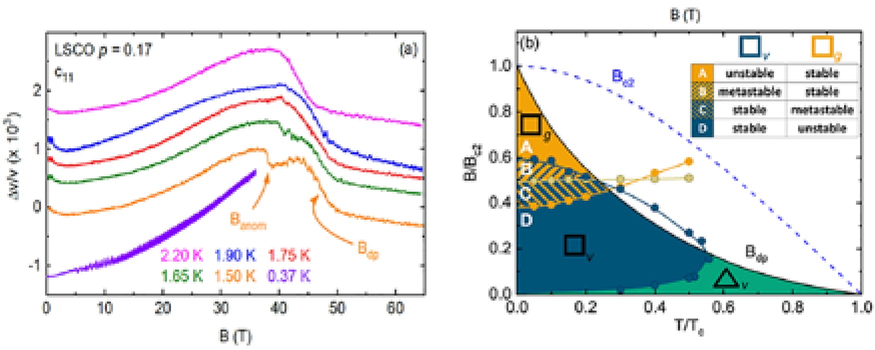

Figure: (a) The change in sound velocity of the in-plane longitudinal mode (c_{11}) of an LSCO crystal with x = 0.17 at different temperatures, as a function of magnetic field. The arrow marks the field of the anomaly, B_{anom}. (b) Theoretical phase diagram showing the different vortex-lattice configurations as a function of T and B. The hexagonal phase is stable in the green-colored area. In regions A and D, two different square vortex lattices are stabilized with a range of metastability emerging in rapidly varying magnetic field shown in regions B and C.

Evidence for a Square-Square Vortex Lattice Transition in a High-T_c Cuprate Superconductor, D. J. Campbell, M. Frachet, S. Benhabib, I. Gilmutdinov, C. Proust, T. Kurosawa, N. Momono, M. Oda, M. Horio, K. Kramer, J. Chang, M. Ichioka, and D. LeBoeuf, Phys. Rev. Lett. **129**, 067001 (2022).

Contact: david.leboeuf@lncmi.cnrs.fr

HIGH MAGNETIC FIELDS UNVEIL STRAIN-INDUCED EXCITON HYBRIDIZATION IN 2D CRYSTALS

Elena Blundo, Antonio Polimeni, Sapienza University of Rome,
Adam Babiński, University of Warsaw, and Peter Christianen, HFML Nijmegen

Strain plays an important role in two-dimensional (2D) semiconductors. Thanks to their all-surface nature, these 2D materials feature an extraordinary capability to bear mechanical deformations without fracturing. This resilience to stress reveals itself a precious property that can be exploited for flexible devices.

Therefore, most studies were devoted to the effects of strain on the electronic, optical, and transport properties of 2D semiconductors, in particular of transition-metal dichalcogenide (TMD) monolayers (MLs). These latter are regarded as a promising platform for quantum optical technologies. In particular, excitons in TMD MLs can be exploited as valley-carrying bits, whose characteristics are embodied in the gyromagnetic (g) factor determinable by magneto-optical spectroscopies.

The interplay between strain and the exciton magnetic moment in TMD MLs has not been investigated. Typical straining devices hardly fit within the bore of a magnet, and performing experiments on strained microscale regions under high magnetic fields is challenging. This hurdle was recently overcome by a series of experiments performed at the EMFL facilities in The Netherlands and at the Regional Partner facilities in Poland within the dual-access scheme of the ISABEL project.

WS_2 MLs were subjected to strong mechanical deformation by creating atomically thin microbubbles filled by highly pressurized hydrogen gas (bottom inset Figure 1). Consequently, biaxial strain values in excess of 2 % can be reached in the bubbles, leading to a reordering of the valence-band states and to a direct-to-indirect exciton transition (top inset of Figure 1). In particular, the strain of the bubbles engenders controllable on/off-resonance conditions between direct and indirect exciton energy levels, which eventually hybridize. Compelling evidence of this phenomenon required the use of intense magnetic fields coupled to micro-photoluminescence measurements (Figure 1) that revealed an unpredicted dependence of the exciton Zeeman splitting on strain. A drastic reduction of the exciton g-factor modulus was found (symbols in Figure 2). Advanced theoretical methods (lines in Figure 2) were required to reproduce the unexpected strain dependence of the exciton g-factor, unveiling the underlying exciton-state admixing.

The evidence of strain-induced exciton hybridization in a 2D system is not only crucial for future quantum electronics applications of 2D materials, but it also opens the doors to novel research in the field. For instance, exciton hybridization could influence the charge-carrier lifetime and radiative efficiency or could represent an important ingredient in understanding and tuning the coupling between different materials in 2D heterostructures.

Strain-induced exciton hybridization in WS_2 monolayers unveiled by Zeeman-splitting measurements, E. Blundo, P. E. Faria Junior, A. Surrente, G. Pettinari, M. A. Prosnikov, K. Olkowska-Pucko, K. Zollner, T. Woźniak, A. Chaves, T. Kazimierczuk, M. Felici, A. Babiński, M. R. Molas, P. C. M. Christianen, J. Fabian, and A. Polimeni, Phys. Rev. Lett. **129**, 067402 (2022).

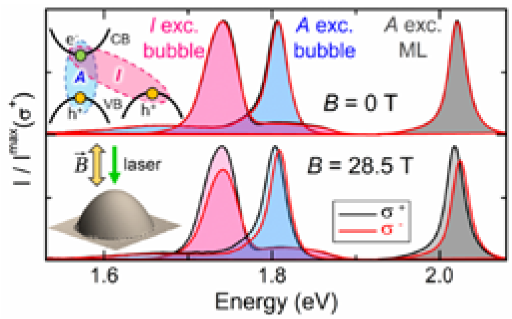

Figure 1: Room-temperature μ-PL spectra at 0 and 28.5 T. Bottom inset: sketch of the magneto-μPL experiment. Top inset: band-structure configuration under strain-driven resonant conditions between the K and Γ points of the valence band.

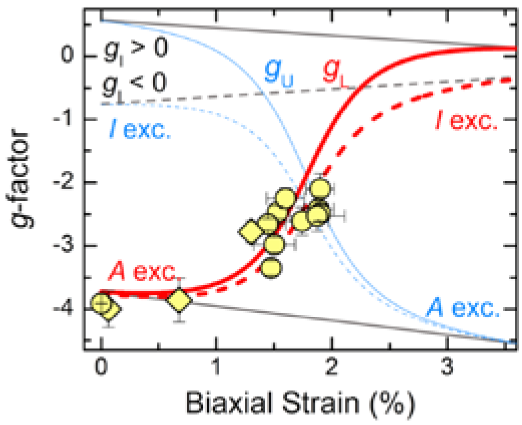

Figure 2: Calculated and experimental g-factors. Diamonds and circles refer to measurements at the Regional Partner facility in Warsaw and at the EMFL facility in Nijmegen, respectively. Gray (colored) lines refer to calculations performed in the absence (presence) of direct-indirect exciton state hybridization.

Contact: Antonio.Polimeni@uniroma1.it, Adam.Babinski@fuw.edu.pl, Peter.Christianen@ru.nl

MAGNETICALLY BRIGHTENED DARK EXCITONS IN TWO-DIMENSIONAL METAL-HALIDE PEROVSKITES

Alessandro Surrente, Wroclaw University of Science and Technology, Paulina Plochocka, Wroclaw University of Science and Technology and LNCMI Toulouse

The synthesis of colloidal nanocrystals with near-unity photoluminescence (PL) quantum yields has vastly extended the potential of metal-halide perovskites for solid-state lighting and display applications. It is possible to template the growth of nanocrystals to form planar, ultrathin perovskite sheets embedded between long organic molecules, which stabilize the colloids, referred to as nanoplatelets, shown schematically in the Figure (a).

These colloidal quantum wells are of interest as highly efficient emitters in the blue spectral region. In the context of light emitters, the splitting between optically dark and optically bright excitons is of paramount importance. After photogeneration, excitons usually relax to the lowest-lying dark state, which is detrimental for the device efficiency.

We performed optical-spectroscopy measurements with an applied in-plane magnetic field to mix the bright and dark excitonic states of $CsPbBr_3$-based nanoplatelets with a different thickness of the lead-halide slab, ranging from two to four layers of lead-halide octahedral plane. The induced brightening of the dark state allows us to directly observe an enhancement of the PL signal on the low-energy side of the spectrum, see Figure (b), which we explain as the magnetic-field induced brightening of the dark state. In-plane magnetic fields allow us to extract accurately the energy splitting between the dark and bright excitons directly, without resorting to further measurements or modelling, see Figure (c).

We also evaluate the ratio between the intensities of the magnetic-field-brightened dark state and of the bright state. This ratio increases quadratically, as expected, but the experimental data can be described only by assuming a temperature of the excitons considerably larger than the lattice temperature, as shown in Figure (d). Thus, the evolution of the PL signal in magnetic field suggests that at low temperatures the exciton population is not fully thermalized, which is indicative of the existence of a phonon bottleneck.

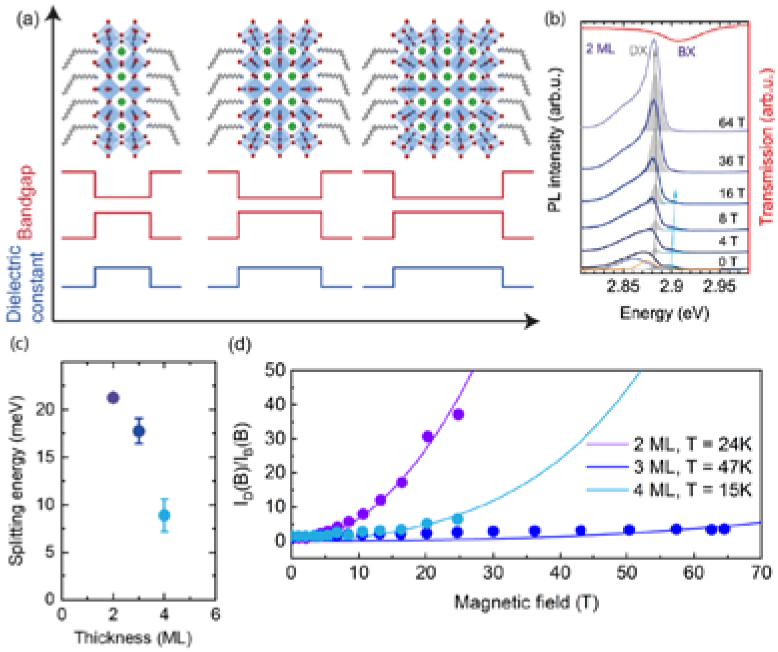

Figure: (a) Top: schematic of the crystal structure of lead-halide perovskite nanoplatelet. Bottom: spatial dependence of the band gap and the dielectric constant. (b) Magneto-PL spectra of nanoplatelets. BX: bright exciton. DX: dark exciton. (c) Measured bright-dark splitting as a function of nanoplatelet thickness. (d) PL intensity ratio between dark and bright exciton states for the three nanoplatelet thicknesses investigated as a function of the applied magnetic field. Full circles represent experimental points. The curves are calculated using the temperature indicated in the legend.

Thickness-dependent dark-bright exciton splitting and phonon bottleneck in $CsPbBr_3$-based nanoplatelets revealed via magneto-optical spectroscopy, S. Wang, M. Dyksik, C. Lampe, M. Gramlich, D. K. Maude, M. Baranowski, A. S Urban, P. Plochocka, and A. Surrente, Nano Letters **22**, 7011 (2022).

Contact: alessandro.surrente@pwr.edu.pl, paulina.plochocka@lncmi.cnrs.fr

MAGNETOCALORIC MATERIALS FOR THE LIQUEFACTION OF HYDROGEN

Tino Gottschall, HLD Dresden

We are witnessing a great transition towards a society powered by renewable energies to meet the ever-stringent climate target. Hydrogen, as an energy carrier, will play a key role in building a climate-neutral society. Although liquid hydrogen is essential for hydrogen storage and transportation, liquefying hydrogen is costly using conventional methods based on Joule-Thomson effect. As an emerging technology which is potentially more efficient, magnetocaloric hydrogen liquefaction can be a "game-changer" here.

In this work, we have investigated the rare-earth-based Laves phases RAl_2 and RNi_2 (R being a rare earth) for magnetocaloric hydrogen liquefaction. We have noticed an unaddressed feature that the magnetocaloric effect of second-order magnetocaloric materials can become "giant" near the hydrogen boiling point. This feature indicates strong correlations, down to the boiling point of hydrogen, among the three important quantities of the magnetocaloric effect: the maximum magnetic entropy change ΔS_m, the maximum adiabatic temperature change ΔT_{ad}, and the Curie temperature T_C.

Results of our measurements of the magnetocaloric effect in static and in pulsed fields are shown in the figure. Moreover, we have developed a mean-field approach to describe these two trends theoretically. The dependence of the magnetocaloric effect on T_C revealed in this work helps researchers quickly anticipate the magnetocaloric performance of rare-earth-based compounds, guiding materials design and accelerating the discoveries of magnetocaloric materials for hydrogen liquefaction.

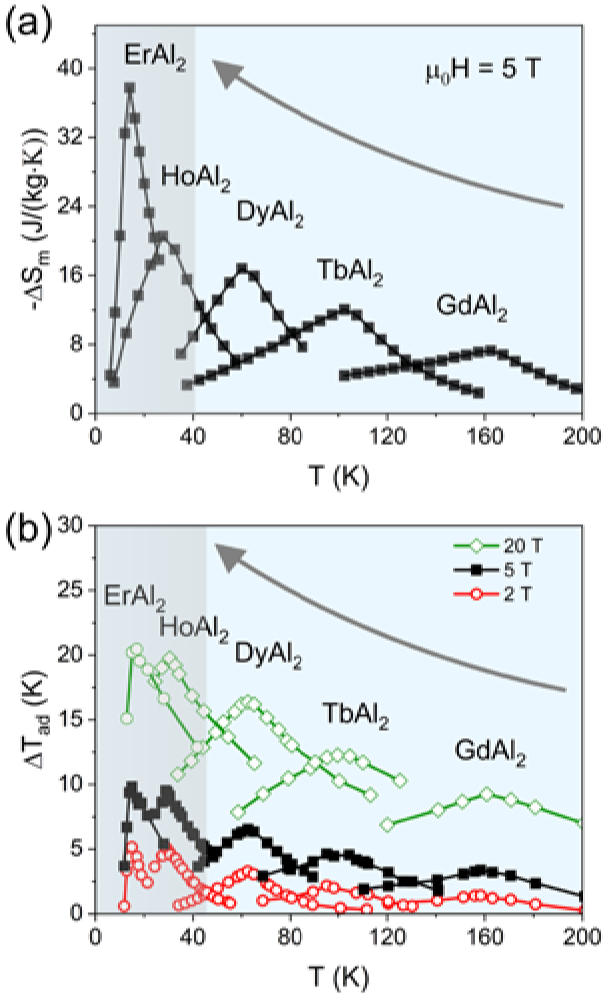

Figure: (a) Magnetic entropy changes in fields of 5 T and (b) direct measurements of adiabatic temperature changes of several Laves-phase materials in pulsed fields of 2, 5, and 20 T.

A study on rare-earth Laves phases for magnetocaloric liquefaction of hydrogen, W. Liu, E. Bykov, S. Taskaev, M. Bogush, V. Khovaylo, N. Fortunato, A. Aubert, H. Zhang, T. Gottschall, J. Wosnitza, F. Scheibel, K. Skokov, and O. Gutfleisch, Applied Materials Today **29**, 101624 (2022).

Contact: t.gottschall@hzdr.de

OPENING OF THE 28TH CALL FOR ACCESS

The 28th call for proposals has been launched on October 15, 2022, inviting researchers worldwide to apply for access to one of the large installations for high magnetic fields collaborating within EMFL.

The four facilities

- LNCMI - Grenoble - France: Static magnetic fields up to 36 T
- HFML - Nijmegen - the Netherlands: Static magnetic fields up to 38 T
- HLD - Dresden - Germany: Pulsed magnetic fields to beyond 95 T
- LNCMI - Toulouse - France: Pulsed magnetic fields of long duration to beyond 99 T and on the microsecond scale to beyond 200 T

run a joint proposal program, which allows full access to their installations and all accompanying scientific infrastructure to qualified external users, together with the necessary support from their scientific and technical staff.

Users may submit proposals for access to any of these installations by a unified procedure. You may find the online form for these proposals on the EMFL website.
www.emfl.eu/user

In the frame of the EU-funded ISABEL project, EMFL will continue to trial the novel **dual-access** procedure. In addition, EMFL has set up a novel **first-time access** mode with the aim of lowering the barrier for researchers to start using the EMFL facilities. Prospective users are encouraged to contact a staff member of EMFL who will offer support in preparing the proposal. Additionally, EMFL will offer reinforced on-site support and reimbursement of travel and accommodation expenses. This will allow for increasing the size and diversity of the user community.

EMFL has launched three further access modes within ISABEL with this call: The novel **fast-track access** mode is permanently open. A convincingly urgent scientific case may be addressed as request to the EMFL Board of Directors (BoD). The BoD will evaluate the request and decide within typically two weeks, but may optionally consult one or more EMFL Selection Committee members and check the feasibility with the facility manager and the local contact. Further, users may apply for **technical-development access**, dedicated to the interest of scientists wishing to develop and improve technical installations and metrological procedures that could also be of interest to other EMFL users. A tailored **long-term access** mode was set up in order to meet the demand for schemes such as complex high-level science cases, which require a sequel of high-field experiments. If positively evaluated, the user will obtain an extended amount of access over a two- to three-year period. Proposals to the latter two access modes must be submitted during the regular call periods and will be evaluated by the BoD as a special category.

Please note that each experiment carried out must be followed up by a progress report and your publication record filled out online on the EMFL website. Please be aware that this information will also be made available to the Selection Committee.

To improve our user program further, your feedback to the user committee is highly appreciated.
Please find the form on the EMFL website.
https://emfl.eu/SelCom/UserCommittee/feedbackform.php

The deadline for proposals for magnet time is November 15, 2022.

A Selection Committee will evaluate all proposals. Selection criteria are scientific quality (originality and soundness), justification of the need for high fields (are there good reasons to expect new results) and feasibility of the project (is it technically possible and are the necessary preparations done). We strongly recommended contacting the local staff at the facilities to prepare a sound proposal and ideally indicate a local contact.

Please do acknowledge any support under this scheme in all resulting publications with „We acknowledge the support of the HFML-RU (or HLD-HZDR or LNCMI-CNRS), member of the European Magnetic Field Laboratory (EMFL)." UK users should, in addition, add "A portion of this work was supported by the Engineering and Physical Sciences Research Council (grant no. EP/N01085X/1)."

- You may find more information on the available infrastructures for user experiments on the facility websites.

www.hzdr.de/hld
www.lncmi.cnrs.fr
www.ru.nl/hfml

EMFL
European Magnetic Field Laboratory

The EMFL develops and operates world class high magnetic field facilities, to use them for excellent research by in-house and external users.

EMFL DAYS 2022 IN KERKRADE, THE NETHERLANDS

This fifth edition of the EMFL Days was organized in Kerkrade from September 19-21. About 120 EMFL staff members gathered right on the Dutch-German border, benefiting from Rolduc Abbey's sublime ambience and a serene autumnal atmosphere.

The aim of the meeting was to continue to learn more about each other's work at the different sites, exchange ideas, and define a common strategy for the future of EMFL. This included scientific work, but as well work on technological and administrative aspects, giving also a podium to express concerns about soaring energy prices. The program was divided into two parts: A formal program with plenary sessions and workgroups dealing with various topics, and an informal program, crowned by a visit to GaiaZOO.

The EMFL Days started on Monday afternoon by a plenary session with an opening and welcome by Peter Christianen, chair of the EMFL Board of Directors. The directors of the three laboratories - Peter Christianen (HFML), Charles Simon (LNCMI), and Jochen Wosnitza (HLD) - presented the current state and future plans of their facilities. Further, Geert Rikken and Xavier Chaud gave overviews on the EU projects ISABEL and Super-EMFL, respectively. An informal evening program closed the day, when staff joined the icebreaking EMFL pub-quiz.

Exchange of information and discussions started Tuesday morning during the two first sessions of the workgroups. This year, the workgroups covered the topics: i) Magnets and facilities development, ii) Instrumentation, iii) Administration/hosting users/communication, and iv) PhD/Post-Doc session. The afternoon was dedicated to an informal tour through Kerkrade, allowing to visit cultural attractions, as well as burning a few extra calories on hiking trails in the pleasant Limburgian surroundings while marveling the few remains standing testament to the long-gone golden age of coal mining in the area. The highlight of the day was a thorough visit of the roughly 100 different species of GaiaZOO, only to be topped by the dinner, disguised as a culinary safari.

Wednesday morning, the groups continued their work during the two last sessions and defined their vision of a common strategy for EMFL. The morning ended with the wrap-up plenary meeting during which the outcome of the different sessions was shared. Looking back, the EMFL Days are ideal for exchanging information between EMFL staff, whether to discuss the development of a project and its opportunities or to stimulate ideas by creating stronger bonds and intensified dialogue between staff as well as by getting to know each other better. Indeed, the spot-on organized EMFL Days 2022 has been a very successful and fruitful meeting.

EMFL staff members, attending the EMFL Days 2022 on September 19-21 in Rolduc Abbey, Kerkrade.

NATIONAL INSTITUTE OF CHEMICAL PHYSICS AND BIOPHYSICS (NICPB/KBFI), CHEMICAL PHYSICS LABORATORY

The National Institute of Chemical Physics and Biophysics (NICPB) is a research institution under public law in Tallinn, Estonia, where the main task of the scientists is research that values academic freedom. The NICPB carries out fundamental and applied research and engages in the development of novel directions in material sciences, gene technology and biotechnology, environmental technology and informatics.

The Chemical Physics laboratory of NICPB runs several NMR instruments, THz and FIR spectrometers, a 14 T PPMS-based vibrating sample magnetometer, and a magnetic/atomic force microscope set-up. The **THz spectrometer** is equipped with 0.3 K bolometers for sensitive detection below 6 THz. The sample environment of the THz setup includes a 17 T SC solenoid with sample temperature down to 2.5 K in Faraday and Voigt configurations and a 12 T solenoid (Faraday configuration) with a dilution refrigerator where the lowest sample temperature is 100 mK. A range of **NMR spectrometers** up to 800 MHz is available for solid-state and high-resolution NMR. There are several cryostats giving access to several decades in temperature. Unique features include the possibility to work down to liquid-helium temperature under magic-angle-spinning conditions (for powder samples) or statically using a goniometer (crystals). Collectively, these instruments allow one to explore magnetism and magnetic interactions in a three-dimensional phase space of frequency, temperature, and magnetic field.

Researchers interested in undertaking experiments at this laboratory under the dual-access scheme can obtain further details by contacting Toomas Rõõm (THz) or Raivo Stern (NMR, PPMS).

Contact: toomas.room@kbfi.ee and raivo.stern@kbfi.ee

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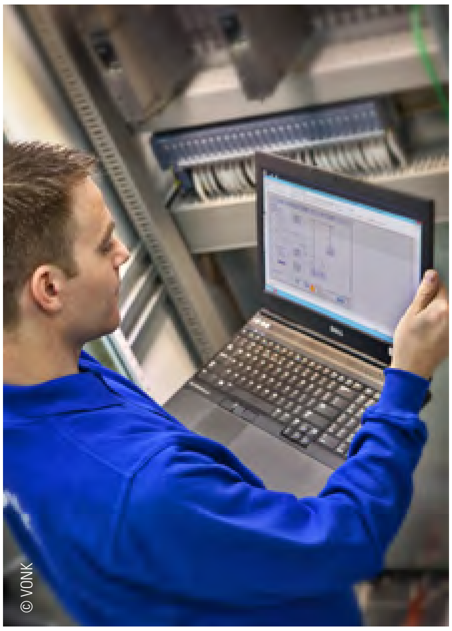
Vonk, a dutch company, is involved in EMFL through the ISABEL European project.



UPCOMING EVENTS

1. 67th Annual Conference on Magnetism and Magnetic Materials (MMM 2022), Minneapolis, USA, October 31 - November 4, 2022.
https://magnetism.org

2. Spectroscopies of Novel Superconductors (SNS 2022), Bangalore, India, December 12-16, 2022.
https://snsbangalore.iisc.ac.in

3. APS March Meeting, Las Vegas, USA, March 5-10, 2023.
https://march.aps.org

4. DPG Spring Meeting of the Condensed Matter Section, Dresden, Germany, March 26-31, 2023.
https://skm23.dpg-tagungen.de

5. Superconductivity Gordon Research Conference: Interactions, Topology and Applications, Les Diablerets, Switzerland, April 30 – May 5, 2023.
https://www.grc.org/superconductivity-conference/2023/

6. International Conference on Strongly Correlated Electron Systems (SCES 2023), Incheon, Korea, July 2-7, 2023.
https://www.sces2023.org

7. International Conference on Magnet Technology (MT-28), Aix-en-Provence, France, September 10-15, 2023.
https://indico.iter.org/event/19/

8. International Conference on Magnetism (ICM2024), Bologna, Italy, June 30 - July 5, 2024.
https://www.icm2024.org

KICK-OFF WORKSHOP OF REMADE@ARI AT THE HZDR

On September 22nd and 23rd, HZDR launched the research infrastructure project ReMade@ARI with a kick-off workshop, which took place as a hybrid event with on-site meeting at the Helmholtz-Zentrum Dresden-Rossendorf. ReMade@ARI will be the central hub for all sectors and research areas in which researchers investigate and develop new materials for a circular economy. It aims to harness the potential of more than 50 analytical research infrastructures throughout Europe, including the HLD and the HFML as facilities of the EMFL. The project has a duration of 4 years and receives 13.8 million euros funding by the EU within the Framework of the Horizon Europe program.

More information is available via **https://arie-eu.org**

HFML
Radboud Universiteit Nijmegen
Toernooiveld 7
6525 ED Nijmegen
The Netherlands
www.ru.nl/hfml

Centre National de la Recherche Scientifique (CNRS)
LNCMI Toulouse
143 avenue de Rangueil
31400 Toulouse
France

Centre National de la Recherche Scientifique (CNRS)
LNCMI Grenoble
25 rue des Martyrs, B.P. 166
38042 Grenoble cedex 9
France
www.lncmi.cnrs.fr

Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
Dresden High Magnetic Field Laboratory
Bautzner Landstrasse 400
01328 Dresden
Germany
www.hzdr.de/hld

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Publisher / Contact:
Helmholtz-Zentrum Dresden-Rossendorf
Bernd Schröder
Phone: +49 351 260-2711
Email: b.schroeder@hzdr.de
contact@emfl.eu

Editorial Staff:
EMFL Board of Directors, Benjamin Piot, Bernd Schröder, Larysa Zviagina

Responsible for the content:
Peter Christianen (peter.christianen@ru.nl), Charles Simon (charles.simon@lncmi.cnrs.fr), Joachim Wosnitza (j.wosnitza@hzdr.de)

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