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Voltage-controlled spin mechanics
A tribute to Wróblewski and Olszewski
The Single-Atom Transistor
Physics in daily life: muddy cyclists
Directory August 2010

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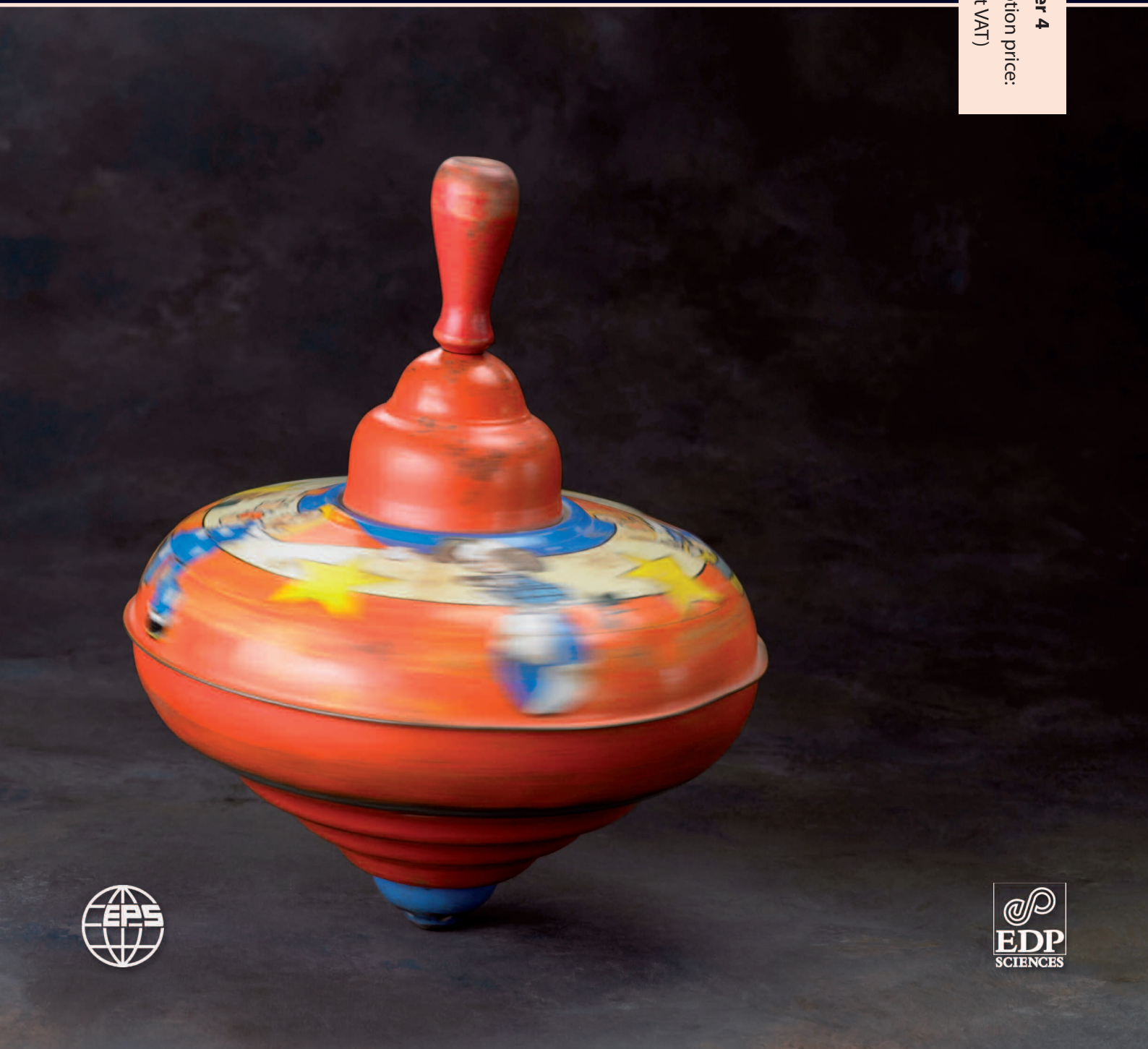

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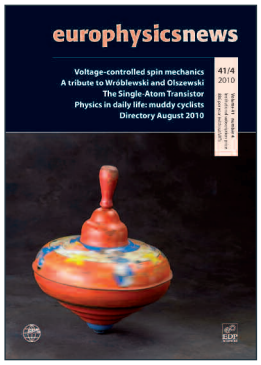

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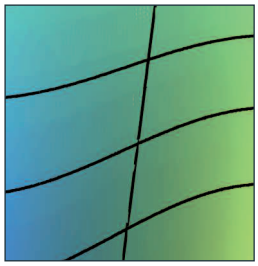
Cover picture: A antique child's spinning toy. ©iStockPhoto
See "Voltage-controlled spin mechanics" p.17.



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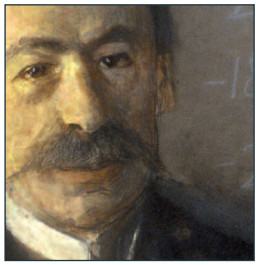
Voltage-controlled spin mechanics



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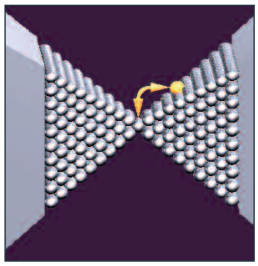
Tribute to Wróblewski and Olszewski



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Forum Physics and Society

goes to El Escorial to address the topics of Science Journalism and Scientific Communication.

Tycho Brahe established Uranienborg at the island of Hven in 1576 - 80. In 1584 he added an underground observatory, named Stjerneborg (Starborg). In its time it was the largest experimental scientific laboratory in the world at a cost of 4 % of the Danish BNP. Even today this level is farfetched. Soon thereafter a new Danish king took power and Tycho lost protection and was forced to leave for Prague. The rest is history.

Today it is not kings that determine the fate of our science system. Our complex societies with their democratic institutions, the media, the electronic revolution and the new and important concept of scientific social responsibility (SSR), substitute for the friendship of one king and not the other.

The financial crisis and major changes taking place in our societies right now, however, have the same dynamics. After a period with strong emphasis on science and technology, new times have hit science (and physics) all over Europe hard and fast. This emphasizes the need for refined tools in maintaining strong stakeholder ship among the many societal players supporting physics and science.

The fourth ***Forum Physics and Society*** will address these burning issues at its meeting in El Escorial, Spain 21-23. October 2010. The assembly will take place right in front of the Palacio Real de El Escorial, the castle of Spanish kings and which was completed in 1584, simultaneously with Tycho's Starborg. The castle still exists, however Starborg was soon to be demolished.

The FPS assembly will address vital topics of importance in defining a stronger bond between the physics community and society at large.

Three topics will be dealt with (i) ***Journalism and Communication of Science***, (ii) **The role of electronic media and scientific responsibility** and (iii) ***Science communication***, a tool for recruiting new students.

These three themes should provide the seed for an overview of the present and future communication landscape and its implications on our societal behaviour. Indeed the development of new information technologies gives rise to new ways of influencing the public opinion and this takes place on internet via websites, blogs, videos (e.g. on YouTube) and other social networks such as Facebook, etc. The actors in this debate can be states or different political or non-political groups. The Forum will concentrate on identifying 'good practices' and issues where EPS and other organizations might have an influence.

The meeting format will be one of select keynote speeches blended with workshops, the aim of which is to formulate written recommendations for the European Physical Society to implement among its national members, divisions and groups. Attendance is limited to 45 participants with a proven interest in the topic as participation requires actual work for the assembly to succeed.

What is then the challenge for physics? The present fiscal crisis has clearly demonstrated the vulnerability of our science endeavour. After a period with stable growth, the societal ownership of science (and physics) has proven to be (too) weak and in need of redefinition. The three assembly topics all circle around the same theme, that of scientific social responsibility and its manifestations in the interface between science and society. The key theme, the renewal of the science system through new talented students coming into physics, is included because our fields of study has declined relative to other tertiary fields of study through the last many years.

The reversal of this trend will not materialize in a business-as-usual model. It will require responsible actions through media, dialogue with the political level as well as a keen understanding of the need for reforms of our present educational setup, including a better understanding of research based learning and the need of Europe's small, medium and large companies. ■

O. Poulsen and M. Ducloy, former Presidents of the EPS
C. Rossel and G. Delgado-Barrio, organizers of the Forum 2010

Links: www.iff.csic.es/fama/con/fps4/intro.html
http://fps.epscommittees.org/madrid-program

EPS Young Minds Project

Promoting the next generation of leaders in physics

Over the centuries European research excellence has been a shining beacon for the international community. Nowadays, it must meet the challenge of keeping such a highly-regarded position in the centuries to come. With this in mind, young researchers are encouraged to take their share of responsibility and engage in outreach activities, international networking and policy discussions, with the full support of EPS.

Boosting the creativity of students and postdoctoral researchers alike, the Young Minds Project (YMP) is the latest initiative of the European Physical Society to promote the next generation of leaders in physics by creating an environment where young physicists assume an active role.

International networking, young researchers involvement with the scientific community, promotion of science among local communities - these should be goals of every young researcher in Europe. Of course, these highly rewarding activities are time consuming and the focus of most young minds is on getting their research tasks done, be it in the lab or in front of a computer. Strong institutional support can be a decisive factor in encouraging young physicists to take an active part in outreach. At the end of February the first meeting of the YMP Action Committee was held at EPS Headquarters in Mulhouse to define the project mission, strategy and roadmap for this initiative. Through the Young Minds Project, EPS aims to encourage all active young scientists, from undergraduates to postdoctoral researchers, to organize local Young Minds Sections that will collaborate to develop scientific, networking and outreach activities.

These Young Minds Sections are composed of at least four members: a president, a vice-president, a secretary and a treasurer. A local senior scientist acts as advisor to the Young Minds Section, providing advice and assistance. Young Minds Sections offer many benefits to their leaders, their members and their local communities: seminars and colloquia can help broaden the knowledge of the members outside their special field of interest; visits to local industries and research labs can boost the integration between industry and research, while providing an outlook on the possible employment possibilities for recent graduates; educational outreach programs to local schools and communities can provide a stimulus for new generations of scientists and increase the awareness for the importance of scientific research in the general public. EPS and the affiliated national societies will provide financial support for such activities through a specific granting scheme. Young Minds Sections can apply for grants, totalling up to 1000€ per year. Deadline for applications: see website. The project is currently supporting three categories of activities: educational outreach (up to 400€), seminars (up to 300€) and networking (up to 300€). The YMP strongly encourages the interaction amongst Sections and students through various levels of international networking: one-to-one exchanges between Young Minds Sections; European-level student conferences; and interaction with the student organizations of other organizations. After its first meeting the action committee set as goal for the first year: the foundation at least of five Young Minds Sections spread all over Europe.

For further information visit the official Young Mind Project website at www.epsyoungminds.org. ■

▼ The ICFO-EPS Young Minds Section in Barcelona has been the first one founded in Europe in April 2010

Antigone Marino, Giovanni Volpe, Armand Niederberger, Ophélia Fornari, David Lee, Maciej Kolwas,
Young Minds Project Action Committee

Gero Thomas Medal 2010

Awarded to Prof. Dr. Gunnar Tibell

In its June 2008 Meeting in Skopje (MK) the EPS Executive Committee decided to award the EPS G. Thomas medal on an annual basis. This medal was created in 2000 in honour of Gero Thomas the Secretary General of the EPS from 1974 till 1999 and is given to individuals for outstanding service to the Society.

Gero Thomas guided the Society through its early years and contributed greatly to establishing its financial stability. Many new Member Societies mainly from Eastern and Central Europe joined EPS during these 24 years. His lasting achievements include the creation of EPL (*European Physics Letters*), Europe's flagship letters journal [see *Editorial* in EPN Vol. **40**, Nr. 1 (2009) p. 3)] and the successful relocation of the EPS Secretariat from Geneva to Mulhouse.

2010 Recipient Prof. G. Tibell

The recipient of the 2010 Gero Thomas medal is Prof. Dr. Gunnar Tibell. He is Professor emeritus in nuclear physics at Uppsala University, Uppsala (SE), where he obtained his doctorate in 1963. After various periods at CERN and after a visiting professorship at University of Maryland and at Osaka University he became professor in Uppsala. He was president of the *Swedish Physical Society* for the period 1989/95. Gunnar chaired first the EPS Education Forum, and later the Pre-university Section of the *EPS Physics Education* Division (holding the School Physics education portfolio). He was consultant at the Royal Dramatic Theatre in Stockholm for the play *Copenhagen* 1999/2000 and wrote music critics in Upsala Nya Tidning. Prof. Tibell was chairman of the *IUPAP Commission 14, The International Commission on Physics Education* (ICPE) (2003/05). He was for many years the president of *International Young Physicists' Tournament* (IYPT), an annual team competition for school pupils (www.iypt.org). Finally, Gunnar was editor of Linné-on-line, an internet project for schools (www.linnaeus.uu.se).

▲ Prof. Dr. Gunnar Tibell

The citation reads:

"The 2010 EPS Gero Thomas Medal for outstanding service to the European Physical Society is awarded to Gunnar Tibell, Professor Emeritus at the University of Uppsala, Sweden. The award recognizes, in particular, Professor Tibell's wide-ranging and influential activities in the area of physics education and his efforts to ensure that physics education at all levels is fully supported and represented within the European Physical Society. In his role as Chair of the EPS Physics Forum, and later within the Physics Education Division, he was an exceptionally vigorous organizer and supporter of a wide range of educational activities, including student mobility programmes, international exchanges for physics teachers, and student competitions, especially the International Young Physicists Tournament of which he was President for ten years. Also noteworthy are his many efforts to coordinate the educational work of the EPS with that of other organizations, such as the International Commission on Physics Education, which he chaired for several years. Thanks to the actions of Gunnar Tibell, European physics education has been enriched by a range of EPS initiatives and the EPS has been enriched by its engagement with a similarly wide range of educational programmes and developments. The Gero Thomas Medal is awarded in apt and timely recognition of Prof Tibell's many contributions to the European Physical Society." ■

H. Ferdinande,
Chairman of the Gero Thomas Medal Committee

A report from ASEPS

Even though the international collaboration in physics research has a long history, Europe-Asia cooperation has remained quite weak, compared to the collaboration between Europe and Americas or Asia and Americas, until the first Asia-Europe Physics Summit, or ASEPS held in Tsukuba, Japan from 24 to 26 March 2010.

This summit was supported by CNRS (Centre National de la Recherche Scientifique) in France and by JSPS (Japan Society for the Promotion of Science) in Japan with KEK (High Energy Accelerator Research Organization) as the administrative organization. The EPS (European Physical Society) and the AAPPS (Association of Asia Pacific Physical Societies) were participating, and both presidents were jointly calling for physicists to attend the summit.

"A balanced cooperation between Europe, Asia, and the Americas is crucial for large scale physics research projects to succeed. ASEPS was held in a hope that this meeting reinforces the Asia-Europe cooperation as a first step towards a true equilibrium between the three main regions, and I believe we made quite a successful step" said Prof. Mitsuaki Nozaki from KEK and co-chair of the summit with Dr. Denis Perret-Gallix from CNRS, France.

With over 200 enthusiastic participants the summit brought together ministry and funding agency representatives, research institutes leaders and researchers in charge of large projects from 31 countries and regions, including the European Union (EU) and the Organisation for Economic Cooperation and Development (OECD).

Another goal for ASEPS was to get the developing countries more involved in basic research in the hope to help bridging the knowledge or digital gap. "We made a big leap to this matter, too. There were so many participants form Asian developing countries such as Pakistan, Bangladesh, Malaysia, Philippines, Vietnam, Thai and Nepal. They did show a strong appeal to pursuing the ASEPS initiative whose main goal is forging a stronger Asia-Europe cooperation in Physics", said Nozaki. ASEPS also welcomed representative from African Physical Society beyond the Europe-Asia connections.

▲ The keynote lecture given by Dr. Makoto Kobayashi, Honorary Professor Emeritus of KEK, and 2008 Nobel prize laureate in Physics. © Physical Society of Japan

Perfect field for global science research

ASEPS covered all areas of physics research, from nanotechnology and energy to medical research and accelerator development. It went even further than that: it looked at the history of collaboration between Asia and Europe and combines lessons learnt from the past with plans for future projects.

"Physics research is the perfect field for initiating the building of a global scientific research governance, because physics is covering a wide scope of research activities. In addition, the physics community has a long experience in international collaboration. We have to identify the obstacles hampering Europe-Asia cooperation and to develop and share a common vision for the future," said Perret-Gallix.

The summit agenda included reports on projects each participating countries and regions were working on, including the keynote lecture given by Dr. Makoto Kobayashi, Honorary Professor Emeritus of KEK, and 2008 Nobel prize laureate in Physics, who explained KEK's scientific activities and international collaboration efforts. Following the lab reports, participants discussed common issues among European and Asian countries, focused on : 1) to build strong collaboration

▼ ASEPS participants gather on the steps of the EPOCHAL Center in Tsukuba. © Physical Society of Japan

for promoting the science projects which will need large-scale experiment infrastructures, 2) to set up a dedicated framework that would enhance Euro-Asia collaborations in physics for the next fifteen to twenty years, 3) to get the developing countries more involved in basic research in the hope to bridge the knowledge or digital gap.

ASEPS Tsukuba Declaration

The main outcome was the "ASEPS Tsukuba Declaration" signed by Jie Zhang, President of the AAPPS and Maciej Kolwas, President of the EPS which acknowledges the importance of strengthening the existing cooperation and implementing new programs in physics research between Asia and Europe to reach a balanced cooperation at the world level. But the Declaration mainly endorses the formation of a task force to examine the roadblocks to Physics research cooperation and actions to overcome them. Another charge for the task force is to propose an appropriate structure to develop and coordinate the Asia-Europe cooperation. "The formation of a task force will give a more formal organization to ASEPS" said Nozaki.

It is a well-known fact to the physics community that any future large-scale project will be a global undertaking, and all regions have to work together to make science projects a reality. The task force to be formed under AAPPS and EPS will initiate this effort by laying down the foundation of a dedicated framework that would boost the level of the Euro-Asia collaborations in physics.

"ASEPS in Tsukuba has started a new movement in research, a movement for a better communication between research, industry, funding agencies and the society at large, a movement to boost the cooperation between European and Asian countries on the road to a more efficient and balanced global cooperation that physics nowadays requires. This movement will find its full expression in a well structured multi-lateral organization." said Perret-Gallix.

Next meeting will be held in 18 months in the fall of 2011 in Wroclaw, Poland that will bear, at this time, the Presidency of Europe. ■

▲ **Jie Zhang, President of the Association of Asia Pacific Physical Societies and Maciej Kolwas, President of the European Physical Society signed a Statement on the first day of the summit. © Physical Society of Japan**

Reproduced with permission from KEK report April 14, 2010, Japan.

Executive Committee Meeting, Mulhouse/F, 21-22 May 2010 - Summary

- President Maciej Kolwas welcomed **president elect** Luisa Cifarelli (mandate 2011-2013), and new **ExCom members** Caterina Biscari (I) and Els de Wolf (NL).
- Minutes of 18/03/2010 have been approved.
- Presentation and short discussion of the **plans of the incoming president**, in particular regarding the visibility of the EPS and the increase of the number of IMs. L Cifarelli's projects concern (among others) the improvement of communication with Divisions and Groups, the reorganization of the ExCom, the raising of funds and the implication of cultural foundations on targeted activities, a renovated series of meetings with the Member Societies, the proposal of an electronic EPS newsletter.
- A new **distribution of tasks for ExCom members** has been proposed, and will be decided in October, the contact list for MS has been updated. M Knoop has been elected honorary secretary of the ExCom.
- The **council format** has been discussed, in particular regarding the distribution of documents, the number of reports, and the possibilities for interaction of the different participants.
- New **EPL editor in chief**, Michael Schreiber, proposed 4 new co-editors, which have been approved by the ExCom. EPL plans a symposium on "Frontiers in Physics" to celebrate its 25th anniversary to be held at the Bavarian Academy of Sciences in Munich, 2-4 sept 2011.
- Brief discussion on **ASEPS** participation and continuity of the forum.
- The subjects proposed by the **strategy working group** have been discussed; ExCom members will send their comments on the existing topics list before June 6th to M Kolwas.
- A structural reorganization of the **EPS secretariat** is considered, a first phase of screening the actual activities in terms of staff allocation has been initiated.
- Reporting of actual results on the **Bologna study** to the European commission has been discussed. The ExCom also evoked the possibility to organize a special session celebrating "10 years of Bologna process" at the SIF conference in Bologna in September 2010.
- The organization of **EPS 15** in August 2011 by the Balkan Physical Union has been discussed.
- During the **Open Session** cooperation and interactions have been discussed with the following guests: A Slaoui, immediate past president of European Materials Research Society - E-MRS; Martial Ducloy, president of French Physical Society – SFP; Christophe Rossel, president of Swiss Physical Society – SPS; and main convener for next Forum Physics and Society, to be held in El Escorial, Madrid, Spain, October 21-23, 2010 on "Science Journalism and Scientific Communication" (see editorial p.3).
- The next ExCom meeting is scheduled on 1-2 october 2010 in San Sebastian, Spain.

Martina Knoop, EPS Ex-Com Hon. Secretary

European Physical Society – Large Facilities Technology Network

EPS-LFTN

Many fields of physics require large-scale facilities for their research, such as astrophysics, geophysics, high-energy physics, fusion, and areas where high-brightness sources of neutrons, ions or photons are required. Europe benefits from a chain of excellent facilities.

Among its stars is the LHC, which just recently started proton collisions. ITER, the first experimental fusion reactor, is also under construction in Europe. With ALBA, XFEL, FAIR, HiPER, W7-X, LMJ… further large devices have just started or are being built or planned for the next decade.

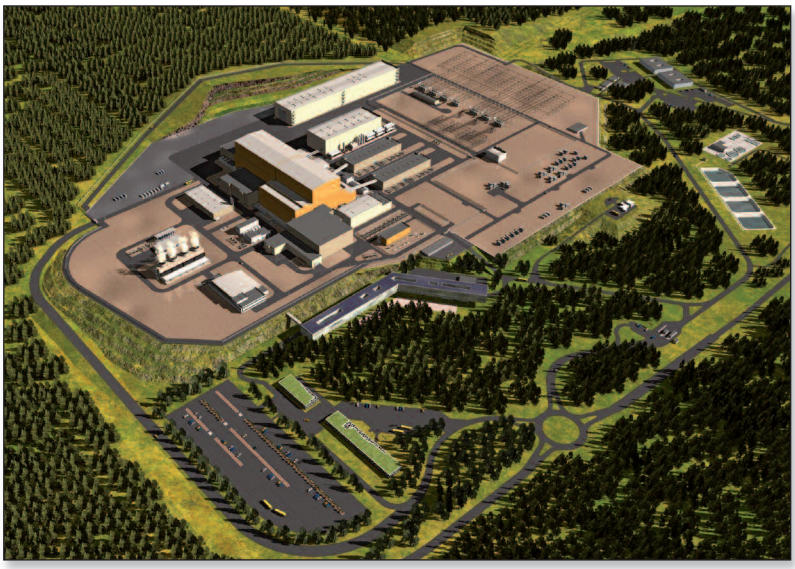
In many of these cases, scientists – often physicists – are given project management responsibility because their scientific background and their membership in an international science community outweigh the nuances of successful management of challenging projects.

The European Physical Society will found a Large Facility Technology Network (LFTN) with members working at the interfaces of physics, technology and project management. The network will bring together the practitioners, the project managers and chief engineers of such projects to facilitate the exchange of ideas, problems, solutions, and expertise in the engineering and managerial development of major physics facilities. The EPS LFTN does not duplicate the work of other organisations and committees like ESFRI but complements them on the working level.

The goals of the Network

The members of the network will exchange knowledge and information on the technical and managerial development of their projects. This will be done mostly by creating a repository and through occasional meetings. The LFTN repository will collect information from its members on technical and managerial issues of research projects and the technical infrastructure of research institutions. The aim of the LFTN repository is to increase the awareness of the different research projects in Europe and the level of engineering and management practice in major physics projects. The Network will specifically lead to or inform on:

- the different technologies represented in the projects of the network (materials, compound materials, bonding techniques, vacuum technologies, cryo-technologies…);
- the sharing of proven technological solutions;
- the technical infrastructure of the institutions represented in the network;
- the different management structures and suggestions for optimising them for specific tasks;
- the availability of a 'pool' of suitably qualified consultants and reviewers for design reviews; it will aggregate expertise and experience across Europe;
- the possibility for the expert pool to provide industrial contract supervision for other client organisations;
- to compare and to recommend engineering tools necessary to develop a project specifically in international co-operations;
- to recommend project management tools for requirements capture/maintenance, planning, risk mitigation, costing, contract supervision, design, analysis, quality control, etc;
- the aspects of quality control mandated by the high standards necessary in research facilities, which often go beyond normal industrial standards;
- the expertise of EU industries; it will provide experience-based guidance on relations between projects and industry;



► An artistic impression of what ITER will look like. The large orange building in the centre is the Tokamak hall, the long building on the right is the winding facility for the Poloidal Field Coils . © ITER Organization

- the proper formulation of Technical Specifications;
- the existence of specific engineering firms (*e.g.* for FE calculations or specific tests)
- the identification of training needs across Europe and their implementation;
- the availability and transferability of project staff (engineers, technicians, assembly personnel);
- to recognise the regulations for safety and licensing in international co-operations, the rules for cross-border, cross-legislation transfer of materials, hardware…and the complexity in international cooperation with in-kind contributions;
- to recognise the issues of intellectual property within a project acting internationally;
- to be aware of the availability of test equipment and surplus equipment elsewhere.

A more in-depth analysis of the goals and potentials of the LFTN is available (fritz.wagner@ipp.mpg.de).

The repository

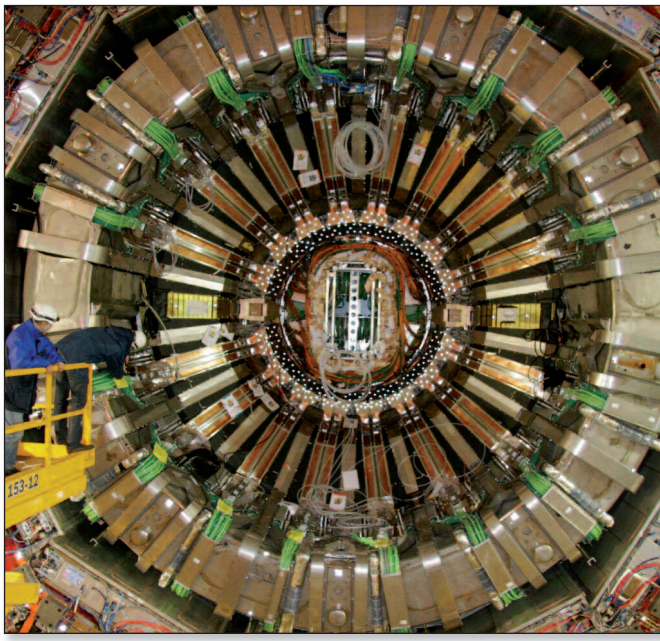
The project information will be collected and stored in a repository located and maintained by the ISN, the Institute for Science Networking, Oldenburg (also providing PhysNet, the worldwide Physics Departments and Documents Network). This key document should briefly describe the objectives and major characteristics of a project (or a technology oriented institution) and should contain examples of generic technical problems solved, technologies used or in use or offered to others, organizational forms and management tools, specific industry connections, telephone numbers and e-mail addresses to contact key people if this need comes up. For this, a keyword based information pool will be built up.

Membership

The LFTN is open to all EU physics institutions with open communication of their results; the network is open for collaboration and can invite observers. At present about 35 projects or institutions with strong technical orientation have shown their interest in the network.

Next step

A one-day workshop is planned during the SOFT conference in Porto, Thursday, Sept. 30. The SOFT conference is Europe's largest fusion technology conference (http://soft2010.ipfn.ist.utl.pt/venue/porto). EPS is grateful to the SOFT organisers for the invitation of the EPS-LFTN. The programme of the workshop is given below. The intention is to have projects describe major technical challenges, and organisational steps, which have proven successful, and to address issues of relevance for others in the spirit of "lessons learned". This part of the programme is complemented by similar talks from industry with strong technological bonds to research or research institutions. ■



▲ A view of the LHC tracker © CERN

Friedrich Wagner, Former President of the EPS

Topic	Speaker	
Welcome, Introduction	C.Varandas, F. Wagner	IST, Portugal EPS
Lessons learned from the construction of the LHC	P. Lebrun	CERN, European Organization for Nuclear Research
Wendelstein 7-X: Lessons learned	Th. Klinger	IPP Greifswald, Germany
Galileo Project	F. Merkle	OHB-System AG, Bremen
The ALBA Project	J. Bordas	CELLS consortium, Spain
High Field Magnet Project for Neutron Scattering	P. Smeibidl	Helmholtz Centre Berlin
The PETRA III project at DESY	E. Weckert	DESY
JET	T. Todd	JET, Culham, UK
Key factors of success in the management of publicly financed large R&D projects	W. Meissner	INTECH, Berlin
In-Kind contributions: A curse or a blessing? The ITER project.	N. Holtkamp	ITER org., Cadarache, France
Status of EPR(tm) light water reactor construction projects	R. Leverenz	AREVA NP, Erlangen, Germany
Management of large projects in industry	E. G. Krubasik	Siemens; Council for Sustainable Development
Goals and organisation of the EPS-LFTN	F. Wagner	EPS
The LFTN repository	Th. Severiens	ISN Oldenburg, Germany

◀ Programme of the EPS-LFTN workshop - Management of Large Technical Projects in Science and Industry - Porto, Portugal, Sept. 30.9.2010. The workshop is embedded into the SOFT conference, Sept. 27th to Oct. 1st (details may still change; updates will be presented at the SOFT conference web-page: http://soft2010.ipfn.ist.utl.pt/venue/porto).

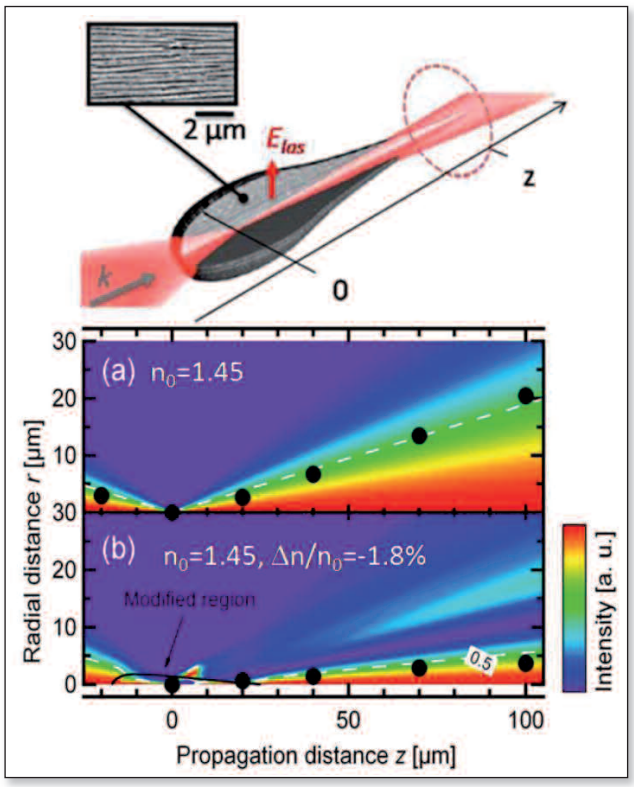
Highlights from europeans journals

OPTICS

Laser nanostructuring to create microlenses in glass

Direct femtosecond (fs) laser writing allows fabricating three-dimensional passive optical devices. However, an important fundamental question is: "what is the maximum refractive index change that can be induced without increasing the scattering or absorption of light?" The answer to this question will determine the range of applications.

In this paper, the authors have succeeded in achieving experimentally a refractive-index reduction of about 2% inside fused quartz. This is the largest refractive-index change so far created in SiO_2. Their work relies on beautifully ordered planar nanocracks that form spontaneously inside silica under repeated fs illumination.



▲ **Probing the properties of the laser-written microlens: The black circles show the measurement of the size (HWHM) of a probe beam as a function of the distance inside fresh (a) and written a-SiO_2 (b). The intensity colour scale image represents calculated intensity beam radial profiles (each normalized to I_{max}) for a refractive index change set at 1.424 (1.8% change from bulk).**

By focusing 800 nm, 130 fs pulses with a peak energy of a few hundred nanojoules 75 µm beneath the surface of fused quartz slabs they form a periodic array of nanocracks which assumes spontaneously the shape of a biconvex lens. Probing how the microlens refracts or absorbs light as a function of pulse energy, they evaluate the refractive index associated with fs laser nanostructuring.

Similar lenses are formed in a variety of glasses using high-fluence fs laser pulses. The exceptionally large refractive change is created without increasing linear absorption or scattering. It is stable and opens a route to fabricating high index contrast integrated photonic devices. ■

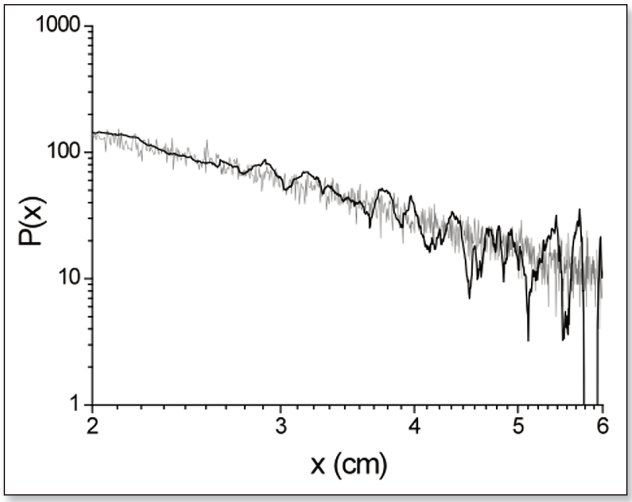
T. Barillot, D. Grojo, M. Gertsvolf, S. Lei, D.M. Rayner and P. B. Corkum,
'High refractive index modification of SiO_2 created by femtosecond laser nanostructuring', *J. Phys. B: At. Mol. Opt. Phys.* **43**, 125401 (2010)

ATOMIC PHYSICS

Anomalous photon diffusion in atomic vapours

Examples of random walks abound in natural and physical systems. Their theoretical description usually involves Gaussian, or normal, statistics that essentially rely on finite first and second moments of the step distribution *P*(x). However, examples of a less common class of random walk phenomena have recently received a lot of attention because their interpretation cannot be accomplished through normal statistics. These systems are governed by step distributions with a

▼ **Distribution function of photons first-step size in a hot resonant Rb vapour. Black solid line: Experimental measurements. Grey line: Monte Carlo simulation. The best fit for both curves is a slow power-law decay $P(x) \sim x^{-\alpha}$, with $\alpha = 2.41 \pm 0.12$, characterizing a heavy-tail distribution and the consequent Levy-flight behaviour of the photons diffusion in this medium.**



pronounced tail, slowly decaying as power laws, with diverging second and/or first moments. They can be described through Lévy statistics, in the frame of a General Central Limit Theorem. Their dynamics is characterized and dominated by rare, large steps, contrasting the normal diffusive behaviour, where the systematic exploration of space by the systems is characterized by a mean free path. Such a super-diffusive behaviour is called Lévy flights transport. Such behaviour has been found in a few biological, chemical, economic and physical systems.

The propagation of photons in scattering media represents a fundamental random walk process in physics. The experimental characterization of the step size distribution in these systems is, however, not straightforward, because the exiting photons have in general suffered multiple scattering processes. Having for the first time experimentally demonstrated that photons multiply scattered in a hot resonant vapour undergo Lévy superdiffusion, we use Monte Carlo simulations to further analyze the frequency redistribution that takes place at each scattering process and that is at the origin of the anomalous diffusion. ■

M. Chevrollier, **N. Mercadier**, **W. Guerin** and **R. Kaiser**, 'Anomalous photon diffusion in atomic vapours', *Eur. Phys. J. D* **58**, 161 (2010)

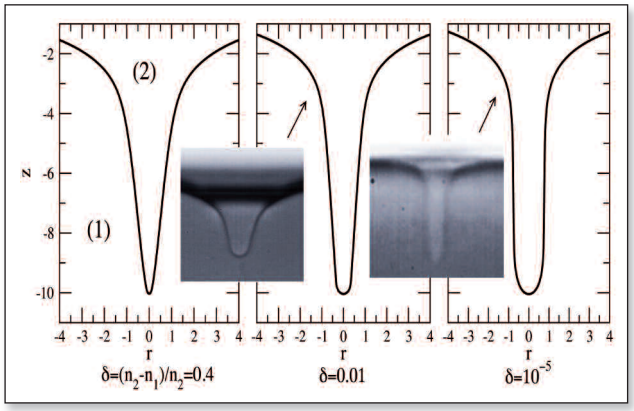
LIQUID PHYSICS

Optohydrodynamics of soft fluid interfaces

Are we able to control and actuate dynamically the shape of a fluid interface at a microscopic scale?

Among the various methods (dielectrophoresis, electrowetting, ...), the recent interest in optofluidics, *e.g.* methods based on the combination of optics and fluidics, promoted innovative approaches using the optical radiation pressure of laser beams to manipulate liquid interfaces.

▼ Equilibrium profiles of a soft liquid-liquid interface bended by a Gaussian continuous laser wave propagating from liquid (1) to liquid (2). Numerical and corresponding experimental profiles are shown for different refractive index contrasts $\delta = (n_2-n_1)/n_2$



Since flows are optically driven, we call this emerging field optohydrodynamics. Beyond exciting academic insights, optohydrodynamics is involved in many interesting applications ranging from interface rheology to adaptive optics or surface relief micropatterning.

We present here an example of optohydrodynamic actuation based on experimental and predictive numerical results (using the Boundary Element Method), which show that the bending of a fluid-fluid interface strongly depends on the refractive index contrast between the two fluids. The characteristic time required to reach equilibrium increases when decreasing this contrast while equilibrium shapes of the deformation switch from a needle-like to a nearly-cylindrical finger. The physical feature at the origin of these behaviours lies in the nonlinear dependence of the optical radiation pressure on the local incidence angle. The viscosity ratio between the two fluids also affects the dynamics of large scale deformations. This investigation illustrates one of the simplest manifestations of optohydrodynamics and provides a frame to anticipate further developments of contactless interface micromanipulation by lasers. ■

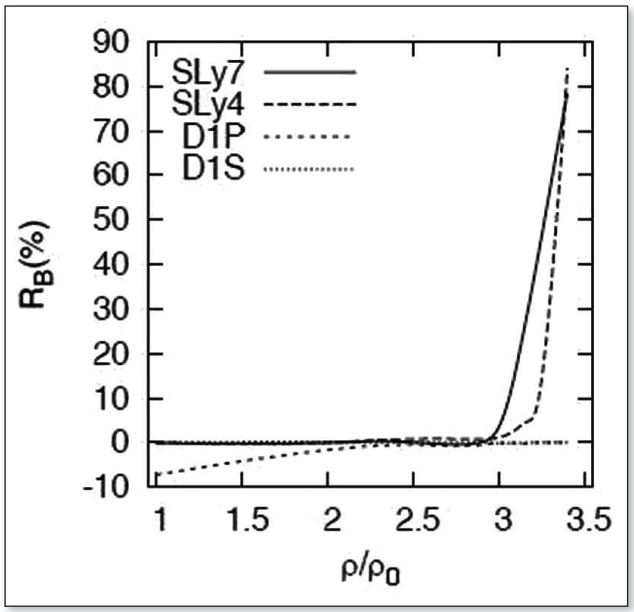
H. Chraibi, **D. Lasseux**, **R. Wunenburger**, **E. Arquis** and **J-P. Delville**, 'Optohydrodynamics of soft fluid interfaces: Optical and viscous nonlinear effects', *Eur. Phys. J. E* **32**, 43 (2010)

PARTICLE PHYSICS

Neutrino mean free paths in spin-polarized neutron Fermi liquids

The study of the behaviour of hadronic matter at high density and low temperature allows to have a deeper understanding of fermionic systems known as Fermi liquids using the theory first developed by Landau in the 1950's. The inclusion of an additional non-zero magnetic field, B, allows further testing properties of possibly magnetized matter. Due to the tiny value of the neutron magnetic moment $\mu_n = -1.9130427 \times 3.1524512326(45)\ 10^{-18}$ MeV G^{-1} in principle huge magnetic fields, like those created on earth in heavy-ion collisions or thought to exist in magnetars, where log B (G) ≈ 15, are needed to get sizable magnetization.

In order to understand how neutrinos diffuse in a magnetized neutron medium like this the neutrino mean free paths (mfp) using the Hartree-Fock approximation with effective nuclear Skyrme and Gogny forces is calculated, with the inclusion of magnetic fields. It is shown that describing nuclear interaction with Skyrme forces and for magnetic field strengths larger than log B(G) = 17, the neutrino mean free paths stay almost unchanged at intermediate densities but they largely increase at high densities when they are compared to the B=0 case. ■



▲ Ratio of neutrino mean free path vs. density for log B = 17 with respect to the B = 0 case calculated for Skyrme (Sly4, Sly5) and Gogny (D1P, D1S) forces for a 15 MeV neutrino.

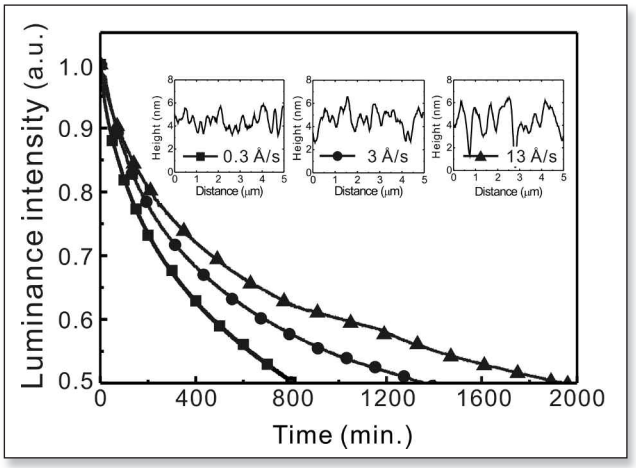
The description with Gogny forces differs from the above mentioned using Skyrme and mean free path stay almost unchanged or decrease at densities in the range (1-2) times that of nuclear saturation density ($n_o = 0.17$ fm^{-3}). The resulting values of the neutrino mean free path can be explained due to the combination of two trends i) common mild variation of the Landau parameters ii) very different values of the nucleon effective mass and induced magnetization of matter as described with the two nuclear parametrizations. ■

M. Ángeles Pérez-García, 'Neutrino mean free paths in spin-polarized neutron Fermi liquids', *Eur. Phys. J. A* **44**, 77 (2010)

MATERIAL SCIENCE

Preparation effects on planar OLEDs properties

Recently, organic light-emitting diodes (OLEDs) have been intensively studied for their various merits in flat-panel display applications. The distinguished characteristics of OLEDs for displays include wide viewing angle, high emission efficiency, and potentially easy fabrication. In addition, their low processing temperatures, and thus versatility in flexible substrates, render them suitable for some novel display applications. However, further improvements in the device reliability and efficiency are paramount before practical applications can be made possible. The behaviour of OLEDs is greatly influenced by the morphology of the organic thin layers. Since several high mobility materials consist of planar-like molecules, we thereby study the effects of the deposition rate on device performance and lifetime of a planar-like Bis(10-hydroxybenzo[h]qinolinato) beryllium ($Bebq_2$) molecule. We have investigated the influence of the deposition rate of the $Bebq_2$ film on the performance of OLEDs with a $Bebq_2$ film as an electron-transporting and emission layer and arrived at three conclusions. Firstly, a low deposition rate enhances the charge mobility and diminishes the photoluminescence efficiency. This result can be attributed to the formation of large aggregation in the ordered molecular domains. Secondly, the electrical characteristics of the devices were found to be consistent with the extracted dependence of the charge transport properties on the film deposition rate. Thirdly, the extracted device lifetime declined with the decrease in the film deposition rate, which could be attributed to the decrease in radiative efficiency and formation of a sharp carrier recombination profile. All was corroborated by photoluminescence efficiency and numerical device simulations.



▲ Half lifetime *vs.* device aging time with deposited rates of 0.3 (■), 3 (●), and 13 (▲) Å/sec of NPB/$Bebq_2$ OLED. Inset is topographic profile of the $Bebq_2$ surface morphology on glass/ITO/NPB.

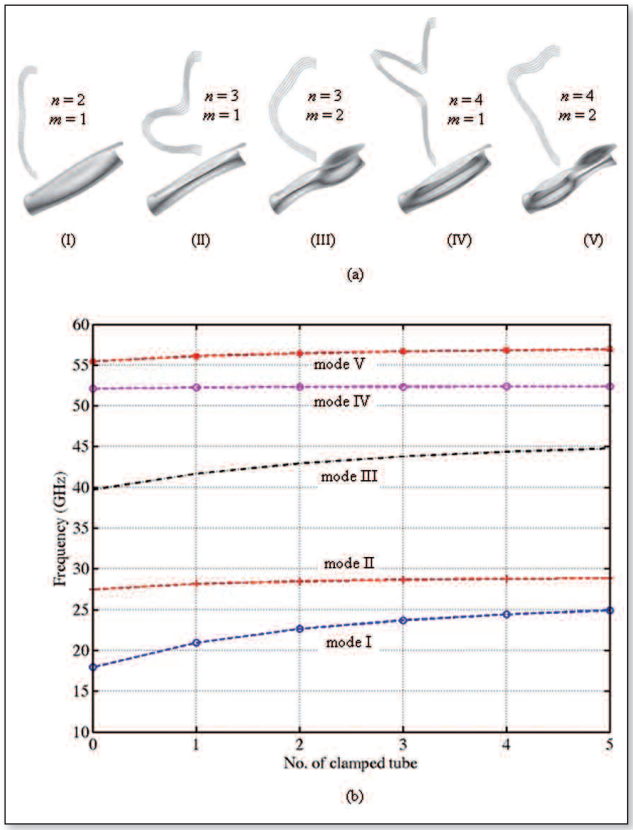
Our study has shown that changing the deposition rate of organic films can alter charge transport properties and molecular radiative efficiency, and thus provides useful insights into the optimization of the OLEDs fabrication process. ■

Chih-Chien Lee, **Shun-Wei Liu** and **Yu-Ting Chung**, 'Effect of deposition rate on device performance and lifetime of planar molecule-based organic light-emitting diodes', *J. Phys. D: Appl. Phys.* **43**, 075102 (2010)

CONDENSED MATTER

Vibrations in multiwall carbon nanotubes

Multiwall carbon nanotubes (MWCNTs) comprise two to dozens concentric singlewall carbon nanotubes (SWCNTs) which are coupled with one another via the intertube van der Waals interaction. The constituent tubes could play significantly different roles in determining the vibrational properties of MWCNTs, which are crucial for a broad range of potential applications of MWCNTs in the next generation of nanotechnology.



▲ **Part (a)** shows the five low frequency vibrations of a five wall carbon nanotubes with the innermost radius 6.8 nm and length 81.6 nm, *i.e.* mode I, II, III, IV and V. **Part (b)** presents the dependence of their frequencies on the number of tubes (constituent tube of the five wall carbon nanotubes) with one end clamped.

In particular, distinct end constraints can be imposed on different constituent tubes of an MWCNT and lead to unique vibrational behaviours of the nanotubule. It is thus of great interest to study the vibration of MWCNTs with heterogeneous boundaries and the influence of the individual tubes on the dynamic stiffness of MWCNTs as coupled systems. To achieve this goal we have performed the very first investigation on these issues by using a computational method. The heterogeneity of the end constraints is obtained by sequentially clamping one end of originally simply supported constituent tubes of MWCNTs. The results show that the clamping process constantly enhances the dynamic stiffness of MWCNTs, which leads to substantial frequency increase up to 50% and sometimes, the alteration of the fundamental vibration mode. Specifically, it is found that the outermost tube of MWCNTs exerts the strongest impacts on the dynamic stiffness of the whole coupled systems. The outcomes of the present study are essential for the development and conceptual design of the MWCNT-based nanodevices/NanoElectroMechanical systems, and provide useful guidance for the future study on the dynamic behaviours of MWCNTs. ■

R. Chowdhury, **C.Y. Wang** and **S. Adhikari**, 'Low frequency vibration of multiwall carbon nanotubes with heterogeneous boundaries', *J. Phys. D: Appl. Phys.* **43** 085405 (2010)

CONDENSED MATTER

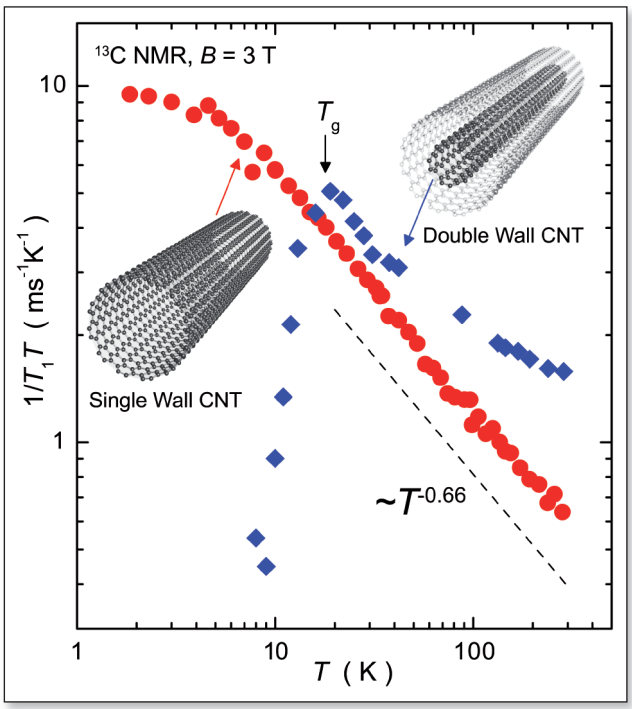
NMR spin lattice relaxation in carbon nanotubes

Electrons confined in one dimension display original properties as they cannot propagate without interacting with each other. Their quantum states cannot be considered as single plane wave-like quasi-particles, and are then described by a specific Tomonaga Luttinger Liquid theory, which yields unusual T^{α} dependencies in most physical quantities. There the exponent α depends of the measured quantity and of the strength of the electron-electron interactions in the specific system.

However systems displaying perfect 1D behaviour are not very common, and it has been long anticipated that carbon nanotubes could be the best realizations of a 1D quantum metal. While evidence for such power laws has been found so far in limited experimental conditions, this work allowed to reveal power law temperature dependence on a large T range on samples consisting of macroscopic bundles of single-wall nanotubes, which had been ^{13}C enriched to permit NMR measurements.

Surprisingly a homogeneous behaviour is found among tubes despite their diverse chiralities and randomly connected nature. The nearly gapless behaviour detected at low T is quite distinct from the large gap detected formerly by the same group on double-wall CNTs. This, together with the actual value of the exponent found, which appears at odds with the simplest theoretical expectations, suggest that we still do not have a full ▮▮▮

▼ **The low energy magnetic excitations in carbon nanotubes is probed by measurements of the ^{13}C nuclear spin lattice relaxation rate $1/T_1$. A power law temperature dependence of $(T_1T)^{-1}$ is observed in single wall CNT in a wide temperature range, but only appears in a limited range for the inner tubes of double-wall CNT, as a large gap in the excitations is detected in that case below $T_g = 20$ K.**



understanding on how to map the simple models to the microscopic properties of the actual physical materials. ■

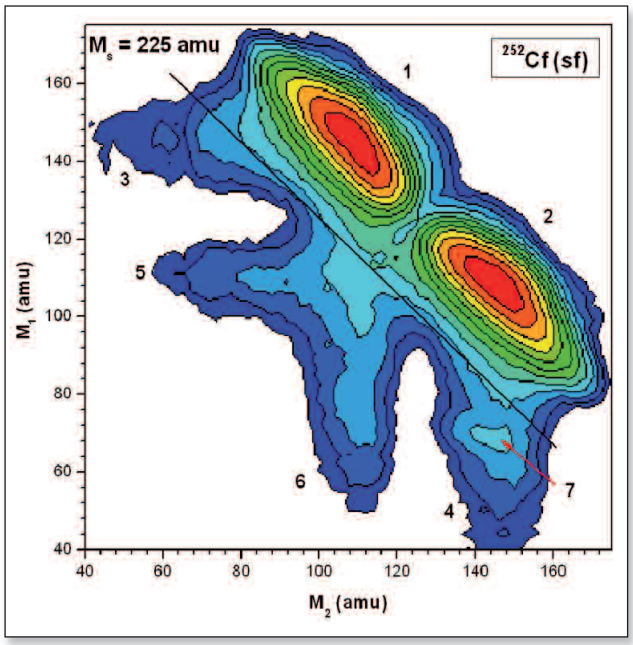
Y. Ihara, P. Wzietek, H. Alloul, M. H. Rümmeli, Th. Pichler and **F. Simon**,
'Incidence of the Tomonaga-Luttinger liquid state on the NMR spin lattice relaxation in Carbon nanotubes', *EPL* **90**, 17004 (2010)

NUCLEAR PHYSICS

Collinear cluster tri-partition ^{252}Cf (sf) and in neutron-induced fission of ^{235}U(n_{th}, f)

Binary fission of a heavy nucleus into two fragments (*e.g.* Ba + Kr) is known since 1938 [O. Hahn and F. Strassmann, Naturwissenschaften 27, 39 (1939)]. A fission process with three fragments ("ternary fission") of comparable mass was mostly considered to show up as a "star" with three fragments with comparable relative angles but was not observed on the level of 10^{-8} per fission. The name "ternary fission" is nowadays usually applied to processes, where light nuclei (^{6}He - ^{28}Mg) are observed perpendicular to the axis defined by the two heavy fragments. In the present work "true ternary fission" is discovered as collinear cluster decay. The discovery relies on the fact that *two* of the fragments emitted into the same direction become separated by an angle of ~1° on their way to the detector while passing through material. One fragment may then be lost by hitting a grid at the detector entry. In the experiments masses and velocities are determined for two fragments observed at relative angles of ~180° in a two arm spectrometer. Evidence for the missing third fragment is obtained using the "missing-mass" approach. In the figure ~10^{+7} fission events of ^{252}Cf(sf) are plotted for M_1 versus M_2. The missing mass of the third fragment is visible as an additional peak (~35000 events) around A=200-212 (arrow) with a probability of 4.7×10^{-3} relative to the binary fissions. Similar evidence was found also for neutron-induced fission of ^{235}U(n_{th}, f). ■

▼ **Contour map of the mass-mass distribution of the fission fragments in ^{252}Cf (sf) detected in coincidence in the two opposite arms of the FOBOS spectrometer. The additional bump (7) is indicated by an arrow.**

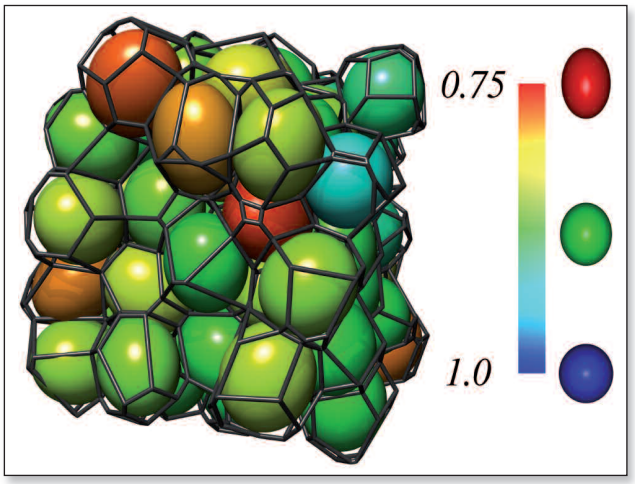


Yu.V. Pyatkov, D.V. Kamanin, W. von Oertzen, A.A. Alexandrov, I.A. Alexandrova, O.V. Falomkina, N.A. Kondratjev, Yu.N. Kopatch, E.A. Kuznetsova, Yu.E. Lavrova, A.N. Tyukavkin, W. Trzaska and **V.E. Zhuhcko**,
'Collinear cluster tri-partition of ^{252}Cf (sf) and in the ^{235}U(n_{th}, f) reaction', *Eur. Phys. J. A* **45**, 29 (2010)

CONDENSED MATTER

Generic Anisotropy of Particle Ensembles

For granular media, liquid crystals, glass-forming liquids and other particle ensembles the concept of *free volume (Voronoi) cells*, that is the space available to each particle, is the principal geometric determinant of physical behaviour. For example, global stability of static packing or flow through the cavities in granular media are evidently results of the local structure. This emphasises the need to understand the local structure and geometry of these structures.



▲ **Voronoi partition of a static disordered packing of spherical beads. The beads are replaced by ellipsoids that match the anisotropy of the cells. (Colours indicate the ratio of smallest to largest half axis.)**

Our study of static disordered granular bead packs shows that the average Voronoi cell in static jammed packs is substantially anisotropic, universally in real experiments imaged by tomography and simulations with and without gravity and friction. Static bead packs are thus globally isotropic structures composed of locally anisotropic environments.

The degree of anisotropy in bead packs is a structural measure that shows a clear signature of both the transition from mechanically unstable to stable configurations (*'jamming'*) and of the onset of partial crystallisation at the random close packing limit. This suggests that the degree of anisotropy may be an order parameter for granular systems.

The local anisotropy of packing of *isotropic* particles may also explain the properties of packing of *anisotropic* particles. If generic packing considerations imply locally anisotropic environments it is a simple leap to assume that anisotropic particles can make more efficient use of this anisotropic space. Indeed, the hypothetical substitution of the bead positions with ellipsoids that match the cell anisotropy gives almost non-overlapping packing with packing fractions similar to those observed experimentally.

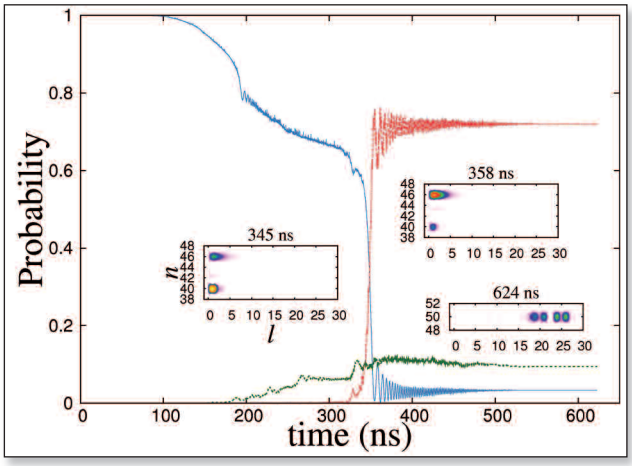
The novel *Minkowski Tensor* method to quantify anisotropy applies to arbitrary spatial structure. Code is available at www.theorie1.physik.uni-erlangen/karambola. ■

G.E. Schröder-Turk, W. Mickel, M. Schröter, G.W. Delaney, M. Saadatfar, T.J. Senden, K. Mecke and **T. Aste**, 'Disordered spherical bead packs are anisotropic', *EPL* **90**, 34001 (2010)

ATOMIC PHYSICS

Multi-photon population transfer in a kicked Rydberg atom

Prohibitively small dipole moments connecting highly excited states of atoms are limiting factors when it comes to population transfer by absorption of a single resonant photon. Traditionally, transfer has been achieved by chirping the photon frequency to induce a series of single photon transitions, carrying the population up to the desired final state. Commonly termed ladder climbing, this method requires a wide range of frequencies to be traversed in order to reach the desired final state. A relatively new alternative technique demonstrated efficient population transfer in Li atoms by adiabatically chirping a microwave field through a multi-photon resonance connecting the two states. Following theoretical investigations showed that besides the quantum resonance picture, the physical mechanism behind the transition could alternatively be explained as a classical transition, taking place in phase space. We exploit this to achieve a significant level of population transfer in a Li atom when the atom is impulsively *kicked*. This is different than previous investigations involving kicked atoms in the sense that here we actually drive a well-defined multi-photon transition with a series of electric field impulses. We were able to achieve roughly 76% population transfer from 40p state to n=46 manifold of Li by chirping the kick frequency through a 6-photon resonance. A small fraction of the population ends up in n=50 due to an accidental 4-photon resonance. The populations just before and after the transition exhibit an angular momentum distribution that substantially resembles that of the initial p-character, which is in stark contrast with that observed using microwaves. ■



▲ **Time evolution of the probabilities to find the atom in 40p state (blue), n=46 (red) and n=50 (green) manifolds of Li. Inserts show the probability distribution in n and l quantum numbers just before (345 ns) and after (358 ns) the transition.**

T. Topcu and **F. Robicheaux**, 'Multi-photon population transfer in a kicked Rydberg atom: adiabatic rapid passage by separatrix crossing', *J. Phys. B: At. Mol. Opt. Phys.* **43**, 115003 (2010)

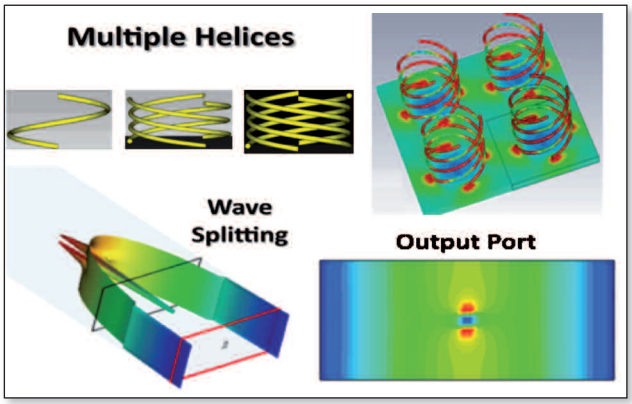
OPTICS

Artificial **multiple helices**

Polarization and electromagnetic properties in artificial multiple helix structures are investigated. It was found that increasing the numbers of helical backbones, resulting in higher values of chirality index, a unique beam splitting behaviour is observed. These split left and right circular polarized waves provide opposite refractive index broad passband, propagating within the structure with very low loss.

Circular polarization and EM responses in artificial multiple helices are investigated. Left (LCP) and right circular polarized (RCP) waves are individually launched in the same direction as

▼ **Artificial multiple helices. Wave splitting, resulting from quadruple helices.**



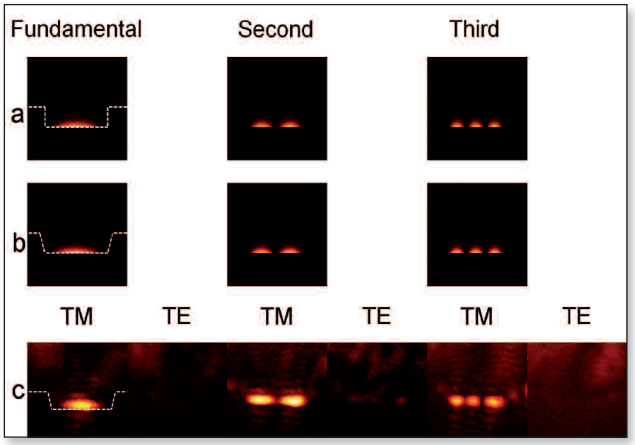
the helix axis. Transmission properties, *i.e.,* scattering parameters and loss factor, as well as EM material parameters, *i.e.,* permittivity, permeability and refractive index from each excitation are obtained using full-wave simulations. Helices are twisted clockwise (right handed or RH) and counter clockwise (left handed or LH) directions to generate the structure's handedness. Helices constructed from different numbers of backbones, from one (single helix) to five (quintuple helix) are studied. Multiple helices are shown to have well-established reverse circular polarization effects. Double helices are proved to have filtering ability; only one of the circular polarized waves can propagate inside the structure stack. As chirality index is increased, a low loss splitting light bandwidth is observed in triple, quadruple and quintuple helices. Helices with three or higher numbers of helical backbones can generate a broad bandwidth of opposite refractive index pass band from the separated LCP and RCP waves propagating inside the structure stack. These properties are beneficial to optoelectronic devices, especially for polarization control and splitting light applications. ■

N. Wongkasem, C. Kamtongdee, A. Akyurtlu and **K. A. Marx**,
'Artificial multiple helices: polarization and EM properties', *J. Opt.* **12**, 075102 (2010)

OPTICS

A trapezoidal plasmonic waveguide

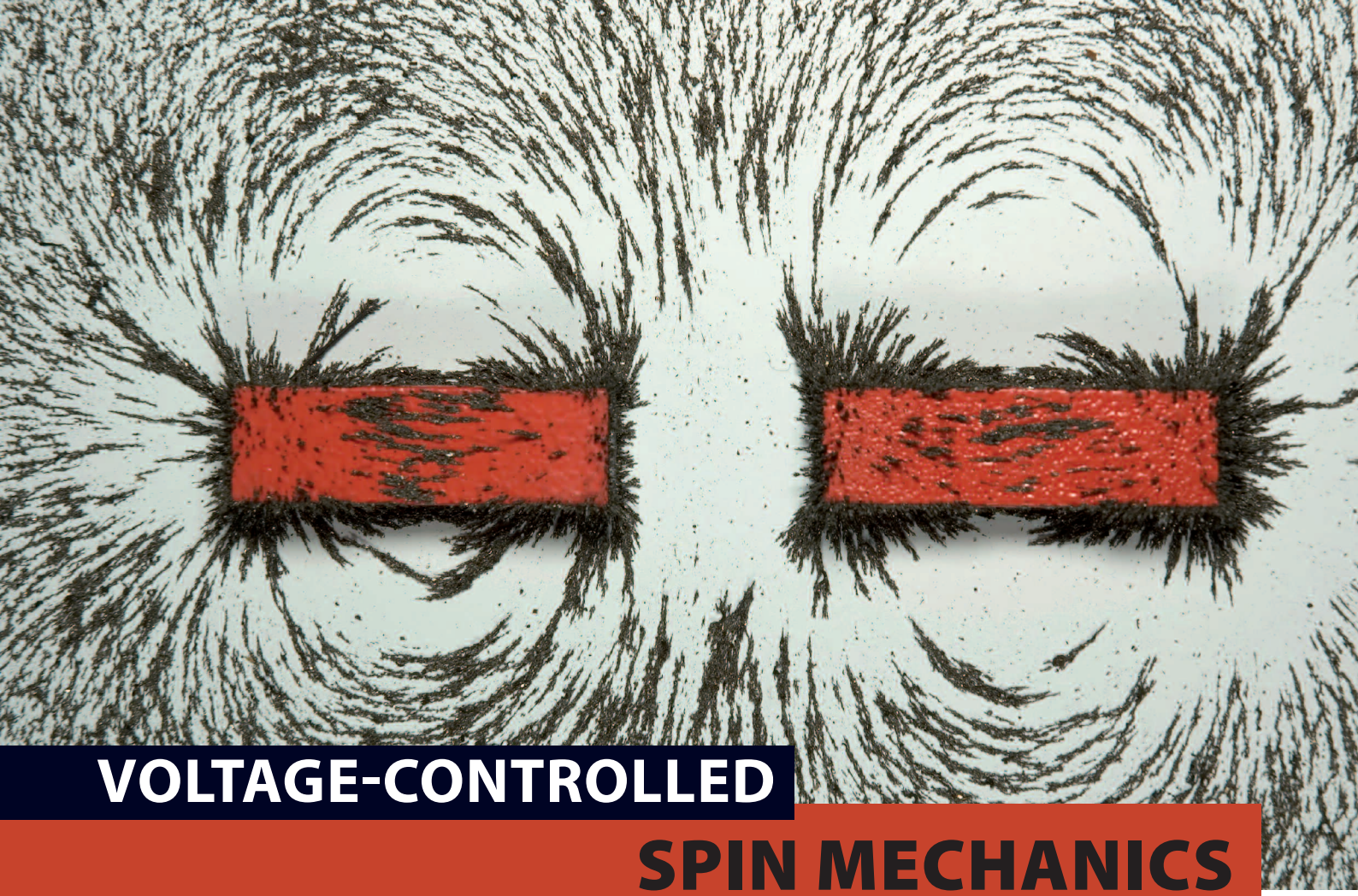
Plasmonic waveguides offer guiding of surface Plasmon polaritons (SPPs), are compatible with biological materials, and have a high sensitivity offered by a field concentration near the surface of the metal. As such SPP waveguides have been adapted for various sensing platforms. We have invented a dual-function Interface Plasmon Polariton (IPP) waveguide, consisting of an SPP waveguide placed at the bottom of a channel whose side-walls provide lateral confinement to the mode (see figure). The device channels biological materials suspended in a fluid and guides SPPs in the same structure, creating a simple and functional bio-sensor ideal for integration into future lab-on-a-chip platforms. We verify good performance of our novel IPP waveguide through experiments and simulation.



▲ **Simulated and experimentally observed mode profiles of the first three lowest order modes. (a) shows the simulated modes of a rectangular waveguide. (b) shows the simulated modes of a trapezoid waveguide. (c) shows the experimentally observed mode profile of the fabricated trapezoid waveguide with the dimensions in (b). The waveguide boundary is marked with a white dashed line around the fundamental mode in each set.**

We have recently experimentally demonstrated an IPP sensor having 1100 nm per unit of refractive index sensitivity. This design is being prototyped for the Natural Sciences and Engineering Research Council of Canada Strategic Network for Bioplasmonic Systems, where the participating researchers are working to perform lung cancer and leukemia early detection. ■

M. Y.-C. Xu and **J. S. Aitchison**,
'Design and experimental demonstration of a trapezoidal plasmonic waveguide', *J. Opt.* **12**, 075003 (2010)



VOLTAGE-CONTROLLED SPIN MECHANICS

* **Sebastian T.B. Goennenwein** * Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, and Physik-Department, Technische Universität München, D-85748 Garching, Germany * DOI: 10.1051/epn/2010401

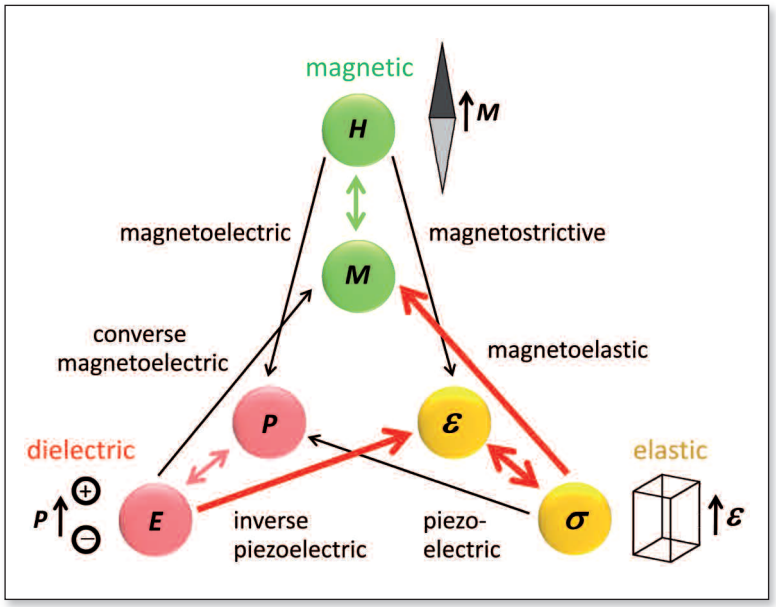
The magnetization of a ferromagnet is usually controlled by means of a magnetic field. In contrast, an electric-field control of magnetization becomes possible in multifunctional ferromagnetic-ferroelectric hybrid structures. The "spin mechanics" scheme discussed here takes advantage of the elastic channel to establish a continuous, reversible, electric-field control of magnetization orientation by up to 90°.

▲ **Magnetic field demonstration with iron filings. © iStockPhoto**

Ferromagnetic materials and devices are exploited in a variety of application fields today, *e.g.*, in magnetic bearings, magnetic actuators, magnetic sensors, or in magnetic data storage devices. Many of these applications require a control of the magnetic properties *in situ*. Since the orientation of the magnetization vector **M** often plays a key role, schemes enabling a *control of the magnetization orientation* are of particular relevance [1]. For example, in computer hard disk drives, the information is stored in magnetic bits – *i.e.*, in regions on the magnetic disk with a well defined **M** orientation. Thus, writing information onto the hard disk is tantamount to (locally) changing **M** in a controlled fashion.

Magnetization Orientation Control Schemes

Several qualitatively different magnetization orientation control schemes are established today. The most natural scheme relies on the magnetic field **H** as the control parameter. Indeed, **M** and **H** are conjugate variables in thermodynamics [2], and the ubiquitous magnetization hysteresis loop **M**(**H**) (see Fig. 3(b)) directly shows that the magnetization orientation can be inverted using an appropriate magnetic field. A very elegant magnetization orientation control scheme relies on the so-called spin torque effect, in which a spin-polarized electric current is exploited to change **M** [3]. This mechanism is particularly efficient in magnetic nanostructures, while in larger devices the Oersted magnetic field produced by the current flow dominates. Last but not least, novel magnetization control schemes are enabled in multifunctional materials [4]. The functionality hereby arises from the combined action of several, distinctively different material properties, as illustrated in Fig. 1 [5]. For example, an electric-field control of magnetization orientation, **M**(**E**), becomes possible if a finite magnetoelectric effect couples the magnetic and the dielectric properties of a given device.



▲ **FIG. 1:** **The interaction between magnetic, dielectric and elastic degrees of freedom yields novel functionalities. An example is an electric-field (E) control of the magnetization orientation (M) [5]. This can either be achieved by exploiting the converse magnetoelectric effect (lower left black arrow), or by a combination of the inverse piezoelectric and the magnetoelastic effect (red arrows). The symbols H and M are magnetic field and magnetization, respectively; E and P are electric field and polarization; and σ and ε are applied stress and elongation or strain.**

A substantial such magnetoelectric coupling can be expected in materials which are simultaneously ferromagnetic and ferroelectric, *i.e.* in magnetoelectric multiferroics [5]. In spite of vivid research activities, however, single phase magnetoelectric multiferroics still are scarce. An attractive and powerful alternative platform are composite materials, in which an electric-field control of magnetic properties indeed is possible [6,7,8,9,10,11]. Such composites are composed of a ferromagnetic constituent, which shares at least one interface with a ferroelectric (or piezoelectric) material. As the composites are multi-phase by design, they do not qualify as multiferroics in the strict sense. In the following, we therefore rather use the term ferromagnetic-ferroelectric hybrids for such artificial, multifunctional heterostructures.

Ferromagnetic-Ferroelectric Hybrids

In ferromagnetic-ferroelectric hybrids, a direct control of magnetic properties via electric fields has been demonstrated [9]. However, this approach is limited by the electric screening length in ferromagnetic metals, which restricts the interaction to a narrow region (a few nanometers at best) at the ferromagnetic-ferroelectric interface. In comparison, the elasto-mechanical interaction between the ferromagnetic and ferroelectric constituents is of much longer range. Such an *electrically controlled spin mechanics scheme* exploits the inverse piezoelectric effect in combination with magnetoelastic coupling (inverse magnetostriction), as indicated by the red arrows in Fig. 1 [6,11]. In the following, we highlight the fundamental properties and the opportunities of the spin mechanics concept.

The Spin Mechanics Scheme

Figure 2 schematically shows a ferromagnetic-ferroelectric hybrid sample for electrically controlled spin mechanics. The ferromagnetic constituent (green ellipse) is mechanically connected to the ferroelectric constituent (orange square). In the hybrid sample concept, this connection can be realized via various techniques, *e.g.*, by growing an epitaxial ferromagnetic film onto the ferroelectric [6,7], by evaporating the ferromagnet onto the ferroelectric [11], or by cementing the two constituents together [10]. The only fabrication requirement is to achieve an efficient strain transfer from the ferroelectric into the ferromagnetic constituent.

The basic idea behind the spin mechanics scheme is the following: Upon the application of a voltage V_p, the ferroelectric will deform because of the inverse piezoelectric effect. The corresponding elastic strain is not restricted to the ferroelectric, but spreads across the hybrid sample. In other words, in an appropriate ferromagnetic-ferroelectric hybrid, the inverse piezoelectric effect in the ferro*electric* allows to establish a voltage-controllable elastic strain in the ferro*magnet*. This strain then influences the magnetization orientation because of the magnetoelastic effect. Taken together, the spin mechanics scheme thus enables a control of the magnetization orientation via the application of an electrical voltage. It is important to emphasize that the (uniaxial) strain in the ferromagnet can be continuously tuned *in situ*, from tensile to compressive, solely by changing the magnitude and the sign of V_p. This process is schematically illustrated Figs. in 2(a) and (b). A positive voltage V_p results in an elongation of the ferroelectric along the vertical (y) direction, which deforms the ferromagnet's initial circular shape into an prolate ellipsoid. In contrast, negative V_p yields an oblate ellipsoid, with a corresponding reorientation of the magnetization vector due to magnetoelastic coupling.

To quantify the impact of the elastic strain onto the magnetic properties, we use the concept of the magnetic free enthalpy F, *i.e.* the appropriate thermodynamic potential [2]. According to the principle of energy minimization, the magnetization vector will point along a direction corresponding to a (local) minimum of F. Thus, in a Stoner-Wohlfarth type of approach, it is possible to calculate the evolution of the magnetization orientation as a function of a given control parameter, by tracking the evolution of the minima of F. Figure 2(c) shows how the free enthalpy changes as a function

of the magnitude and the sign of V_p. The $F(\Theta,V_p)$ curves were calculated with the free enthalpy parameters experimentally determined in a Ni thin film-piezoelectric actuator hybrid sample [11], see Fig. 3(a). Because the thickness of the ferromagnetic film is several orders of magnitude smaller than its lateral dimensions, strong demagnetizing fields constrain **M** to the film plane. The angle Θ between **M** and the **y** direction thus suffices to quantify the magnetization orientation in the film plane. As evident from Fig. 2(c), for large, negative voltages V_p, the global minimum of F is at Θ = 0°. **M** thus points along **y**, as schematically indicated by the red arrow in Fig. 2(b). Upon increasing V_p the free enthalpy minimum gradually shifts towards larger Θ values, and approaches Θ = 90° for large, positive V_p. The magnetization thus rotates to the right (see Fig. 2(a)). In summary, the magnetic free enthalpy picture thus suggests that a continuous, fully reversible, electric voltage control of the magnetization orientation by up to 90° should be possible within the spin mechanics scheme.

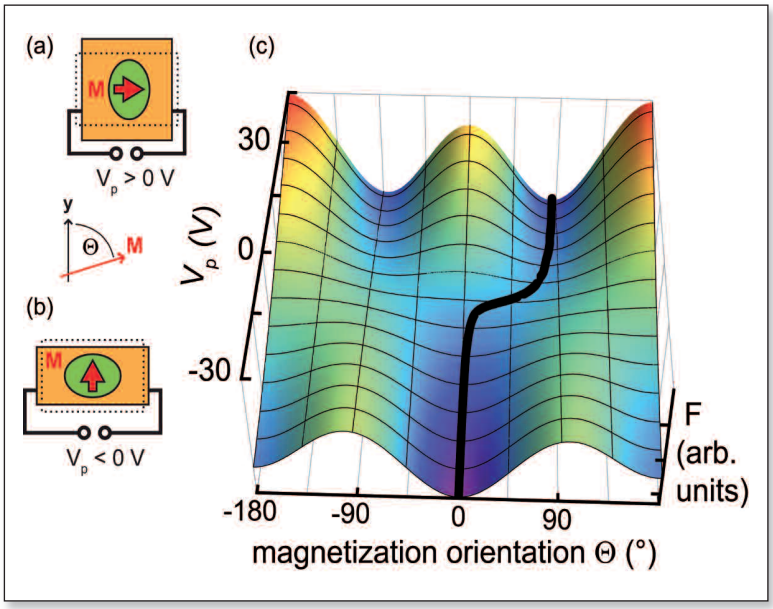
Voltage Control of Magnetization Orientation

Figure 3 demonstrates the voltage control of magnetization orientation in a real spin mechanics hybrid. The ferromagnetic-ferroelectric hybrid sample used in these experiments consists of a 70 nm thick ferromagnetic nickel disk, evaporated onto a commercially available piezoelectric actuator (Fig. 3(a)) [11]. The piezoelectric actuator in fact is made of a fine grained ferroelectric ceramic, which exhibits a strong inverse piezoelectric response, and thus yields reproducible, voltage-controllable elastic strains. Figure 3(b) shows a conventional $M(H)$ magnetization hysteresis loop (full grey line) of the hybrid sample, recorded at room temperature with $V_p = -30$ V applied to the actuator. For the spin mechanics experiments, the Ni film first is magnetized into a single domain state by applying a large positive magnetic field. Then, the magnetic field strength is reduced to zero (point A in Fig. 3(b)), and kept constant throughout the following, voltage dependent measurements. As evident from Fig. 3(c), a substantial voltage control of magnetization is possible. Starting from the large positive magnetization value at point A, M decreases and nearly vanishes with increasingly positive V_p (point B). Upon decreasing V_p back to negative values, M recovers to its initial large value (*cf.* point A). The hysteresis in $M(V_p)$ can be quantitatively traced back to the hysteretic expansion and contraction of the actuator. Note also that the experimental data shown in Figure 3(c) correspond to several, consecutive voltage cycles. The $M(V_p)$ evolution thus is reversible and fully reproducible. For comparison, the $M(V_p)$ loop calculated from the free enthalpy landscape (see Fig. 2(c)) is also included as a full line in Fig. 3(c). Considering that the entire 2 mm diameter nickel disk is treated as one single magnetic domain in the Stoner-Wohlfarth calculation, the agreement between experiment and simulation is fully satisfactory.

Taken together, the magnetometry data presented in Fig. 3 exemplarily demonstrate that in ferromagnetic-ferroelectric hybrids, the magnetization orientation can be continuously rotated back and forth within a range of approximately 90°, simply by applying an appropriate electric voltage V_p. Indeed, one can show that the *reversible* voltage control of magnetization orientation is limited to a range of ≤90° in the spin mechanics scheme, given that the external magnetic field strength is kept constant (zero) [10,11]. Furthermore, if the magnetization is prepared into a metastable initial state (a local minimum of F) via a dedicated magnetic field sweep, a one-shot, voltage-controlled, 180° magnetization reversal is possible. Voltage controlled spin mechanics thus is a viable pathway for the electric field control of magnetization orientation. The scheme is fully operational at room temperature, and in technologically relevant ferromagnets.

The **spin mechanics scheme** enables a **control** of the **magnetization orientation** via the application of an **electrical voltage**

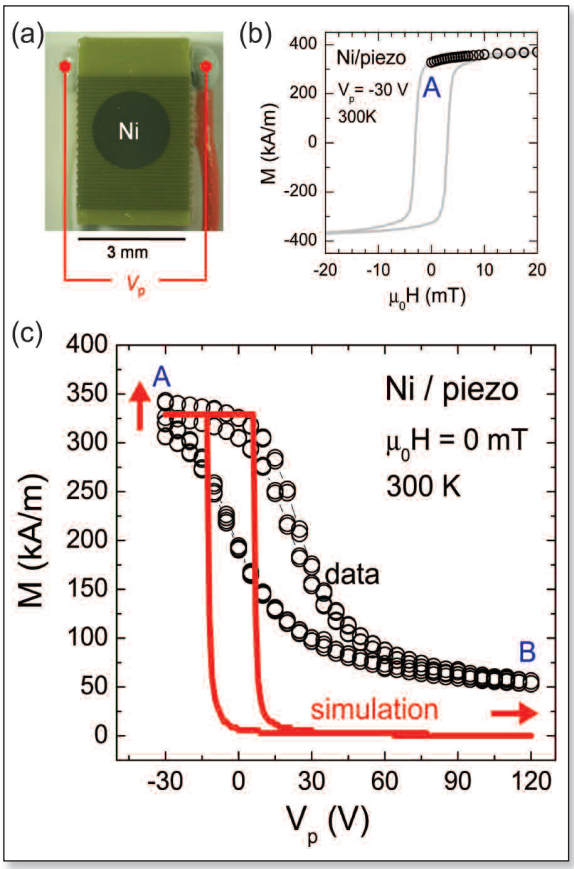
▼ **FIG. 2: (a), (b)** Sketch of the ferromagnetic-ferroelectric hybrid samples for spin mechanics. Depending on the polarity of the voltage V_p applied, the ferroelectric (orange) expands (panel **(a)**) or contracts (panel **(b)**) along the y direction. This induces an elastic strain in the ferromagnet (green) affixed to the ferroelectric, and thus enables a voltage control of magnetization orientation. The red arrows show the magnetization vector M for the two strain states. The elastic deformations are greatly exaggerated for clarity. **(c)** The magnetic free enthalpy F of a nickel thin film-piezoelectric actuator hybrid [11] changes as a function of the voltage V_p. The full black line traces the global minimum of F; Θ is the orientation of M in the ferromagnetic film plane with respect to y. Note also that for the sake of simplicity, the free enthalpy was calculated for a constant, small magnetic field $\mu_0 H = 1$ mT, oriented at 10° to y within the magnetic film plane. This ensures a single, unambiguous, global minimum in F for any given V_p.



Requirements for Voltage-Controlled Spin Mechanics

To achieve a large-angle voltage control of magnetization in spin mechanics devices, several requirements must be met. (i) Voltage-controllable elastic strains of sufficient magnitude must be generated in the ferromagnetic film. This implies that the ferroelectric "stressor" layer dominates the elastic properties of the hybrid. One possibility to fulfill this requirement is to integrate a ferromagnetic film with a ferroelectric which is at least one order of magnitude thicker (cf. Fig. 3). A promising alternative are micro-electro-mechanical systems (MEMS) incorporating a ferromagnet. (ii) Only ferromagnets with finite (large) magnetostriction qualify for the use in spin mechanics hybrids. (iii) The magnetoelastic contribution to the free enthalpy must be dominant in a given plane of interest – an important constraint in particular for spin mechanics hybrids made from single crystalline ferromagnets [10].

▼ FIG. 3: (a) Micrograph of a Ni thin film-piezoelectric actuator hybrid sample [11]. **(b)** Conventional $M(H)$ loop of the hybrid sample. After the application of a large positive magnetic field, the Ni film is in a well defined magnetic state at $\mu_0 H = 0$ mT (point A). **(c)** The magnetization of the spin mechanics hybrid substantially changes as a function of the electrical voltage applied (open symbols). The $M(V_p)$ evolution is reversible and reproducible. The full red line depicts $M(V_p)$ calculated from the magnetic free enthalpy in a Stoner-Wohlfarth approach. The red arrows schematically show the magnetization vector at points A and B, respectively.



Outlook

With the concept of voltage controlled spin mechanics established, many questions related to both basic research and to applications still remain to be answered. One important research direction deals with the electrical generation and/or control of magnetic texture, *e.g.* using an array of micro- or nanopatterned electrodes to generate position-dependent elastic strain, which then in turn yields a position-dependent magnetization orientation. The properties and the control of ferro*electric* domain patterns and their impact on the *magnetic* texture in epitaxial ferromagnetic-ferroelectric hybrid structures is one important challenge in this regard. Another important step is to transfer the spin mechanics concept from DC to high frequencies. Using magnetic MEMs or acoustic waves to generate high frequency elastic strain fields, magnetoelastically driven spin dynamics up to GHz frequencies can be investigated. This enables the study of ferromagnetic resonance phenomea, such as the interaction between spin wave modes and high-frequency elastic modes. ■

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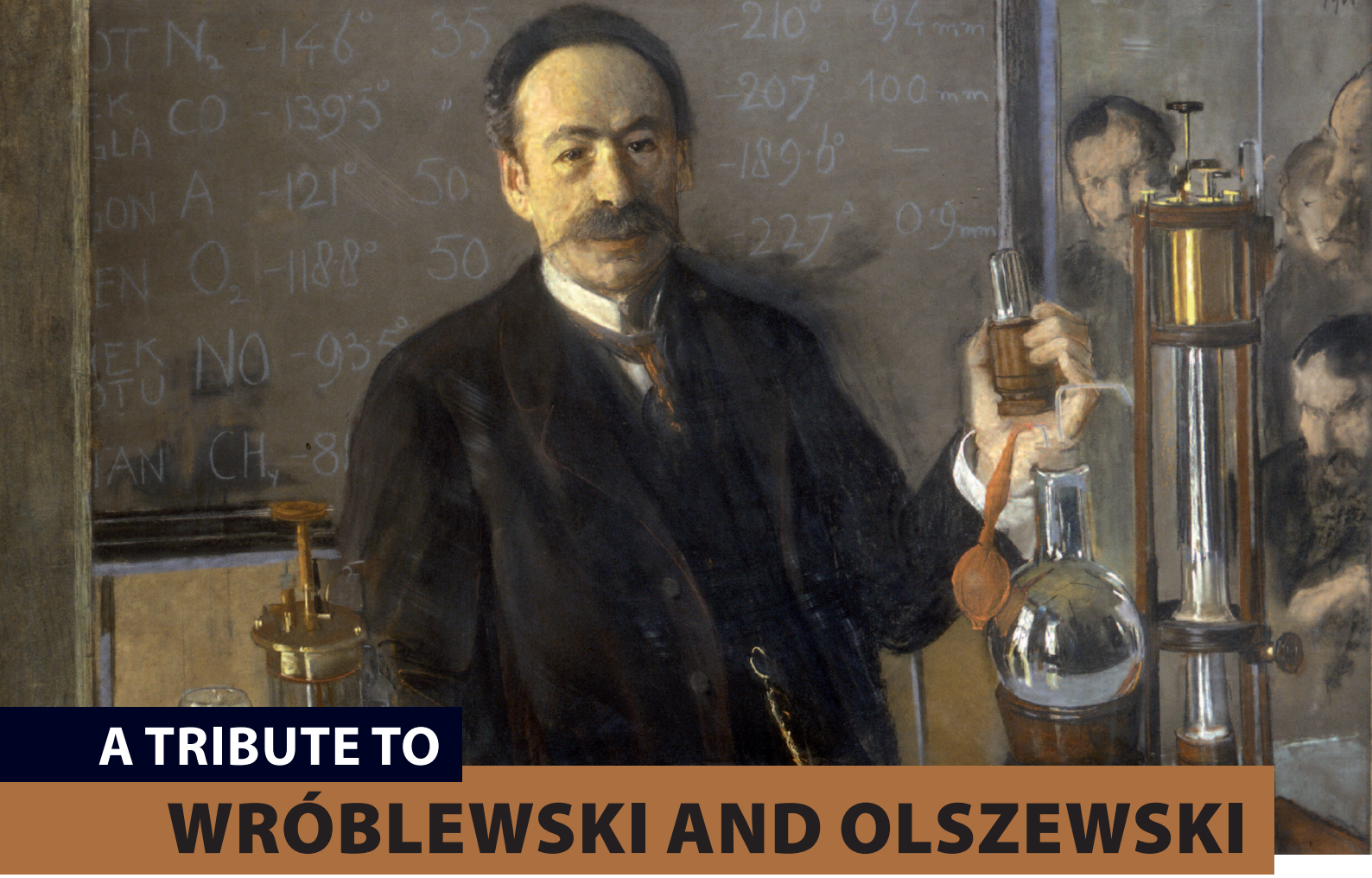


A TRIBUTE TO WRÓBLEWSKI AND OLSZEWSKI

* Henk Kubbinga * University of Groningen (The Netherlands) * DOI: 10.1051/epn/2010402

Poland still vividly remembers its era of greatness. These were the days of Mikolaj Kopernik and his later followers Jan Brozek, the mathematician, and Stanislaw Pudlowski, who, in 1640, met Galileo at Arcetri. More recently Zygmunt von Wróblewski (1845-1888) and Karol Olszewski (1846-1915) acquired continental standing through their liquefaction achievements.

Zygmunt von Wróblewski was born in Grodno, Lithuania, as the son of a lawyer. His academic studies, at the University of Kiev, were interrupted in 1862 after the January Revolution in Poland: because of his participation, Wróblewski was bannished to Siberia. In 1869 he was amnestied and allowed to study successively in Berlin and Heidelberg; in Munich he passed the PhD (1874). Through a stipend of the Cracow Academy of Sciences, Poland's oldest scientific institution, Wróblewski made a grand European tour, visiting Strasbourg, Paris, London, Oxford and Cambridge. In September 1882 he was nominated at Cracow's Jagiellonian University as head of the Physics Department. At Paris he had made the acquaintance of Louis Paul Cailletet in the latter's laboratory, where the liquefaction of gases, one of the major themes of 19th century physics, determined the agenda. With the support of Olszewski, Wróblewski launched a programme of his own, with apparatus brought with him from France.

Karol Olszewski was a native from Broniszow, Poland, who studied at the universities of Cracow and Heidelberg; at Heidelberg he had earned a PhD in chemistry (1872). At his *alma mater*, he became the assistant of the chemist Emil Czyrnianski. In this position he made the acquaintance of Wróblewski, on the latter's arrival. Czyrnianski was kind enough to allow his assistant to join forces with the newcomer, if only because of the latter's cutting edge instruments.

▲ Painting of Olszewski at work, with some of his equipment (by J. Wynosz, 1905).

Liquefaction fever

Early in the 19th century the age-old molecular theory had been generalized by Laplace in the framework of the brand-new doctrine of three states of aggregation and its corollary, the theory of heat. Each and every substance was expected to have a melting and a boiling point and, depending on the atmospheric pressure, to be capable of passing through the three states. New substances challenged both chemists and physicists. One of these was a yellow solid that emerged when (wet) chlorine gas was

► FIG. 1: Aquarel of Zygmunt von Wróblewski by H. Wdowiszewski (around 1884).

cooled down. For a while it was thought to be *solid* chlorine. In 1823, Michael Faraday established its nature and composition: chlorine hydrate ($Cl_2.10H_2O$). He put a sample in a bent tube, sealed it carefully and heated it. The result was a double layer of liquids, the lowest being deep yellow: apparently liquid chlorine. The cooling agents of the time were ice-salt mixtures, which, depending on the salt, reached at best about minus 50 degrees Celsius. This was not particularly impressive, given the existence of an absolute zero of temperature, at minus 266,66 degrees on the same scale, as calculated by Clement and Desormes (1819). High pressures as such were hard to realize for the time being. The *in situ* production by chemical reactions of high pressured gases, then, was an attractive alternative. So Faraday succeeded in producing liquid carbonic acid by putting concentrated sulphuric acid and ammonium-carbonate in the two legs of a bent tube. After sealing it, he mixed the reagents by shaking and noticed again a two-layers' system of liquids. The reaction mixture could, of course, also be subjected to cooling with ice-salt, but in this case the cooling was without avail. Further progress had to wait for the 1840's when Charles Saint-Ange Thilorier discovered a new, truly ground-breaking cooling agent, namely *solid* carbonic acid in liquid ether, capable of attaining -110 °C. 'Thilorier's mixture' became a revelation in the hands of Faraday. The experiments were not harmless, to say the least, as Faraday repeatedly experienced himself.

► FIG. 2: Self-photograph on sepia-paper of Karol Olszewski (around 1884).

In the summer of 1822, Cagniard de la Tour (Paris) had observed something peculiar outside mainstream physics. When a sealed tube filled with ether for about half its volume was heated, *all* of the liquid passed into the gaseous state, notwithstanding the huge pressure of 37-38 atmospheres. The temperature was about 200 °C. The Cagniard phenomena were reconsidered by the Russian chemist Mendeleev in 1859-1861 during a stay at Heidelberg, while studying the dilatation of liquids above their boiling points in sealed tubes. There was a particular temperature at which that cohesion was expected to vanish, just like the latent heat of evaporation. For ether that temperature would be about 190 °C. Mendeleev called it the 'absolute boiling point'.

Early in 1861, Thomas Andrews (Belfast) set out to focus on carbonic acid and air. His results appeared in print only in 1869 under the title 'On the continuity of the gaseous and liquid states of matter'. This seminal paper contains the notion of a substance's 'critical temperature'. James Thomson and Johan van der Waals were to elaborate on it. In the early 1870's it was recognized, then, within the framework of the kinetic theory, that each substance was characterized by a particular temperature at which the liquid continuously changed into a vapour, and *vice versa*, as if there were no longer latent heat involved.

The 'dynamic' and 'static' states of a liquid

On 24 December 1877 the Paris *académiciens* heard of two major innovations concerning oxygen. One of the communications–cabled two days before from Switzerland–came from Raoul-Pierre Pictet (1846-1929) of the University of Geneva. Pictet was a cryogenic expert who had used his expertise for the construction of artificial ice skating rinks. He announced the production of a jet

of liquid oxygen. His technique implied the stepwise cooling of high pressured oxygen gas, freshly prepared by pyrolysis of potassium chlorate ($KClO_4$). The oxygen produced was at a pressure of 320 atmosphere and once at -140 °C, it was allowed to suddenly expand by opening a cock. A jet of liquid oxygen escaped, the remaining part being further cooled. In all this, Mendeleev's 'absolute boiling point' or Andrews' 'critical temperature' did not play any role at all.

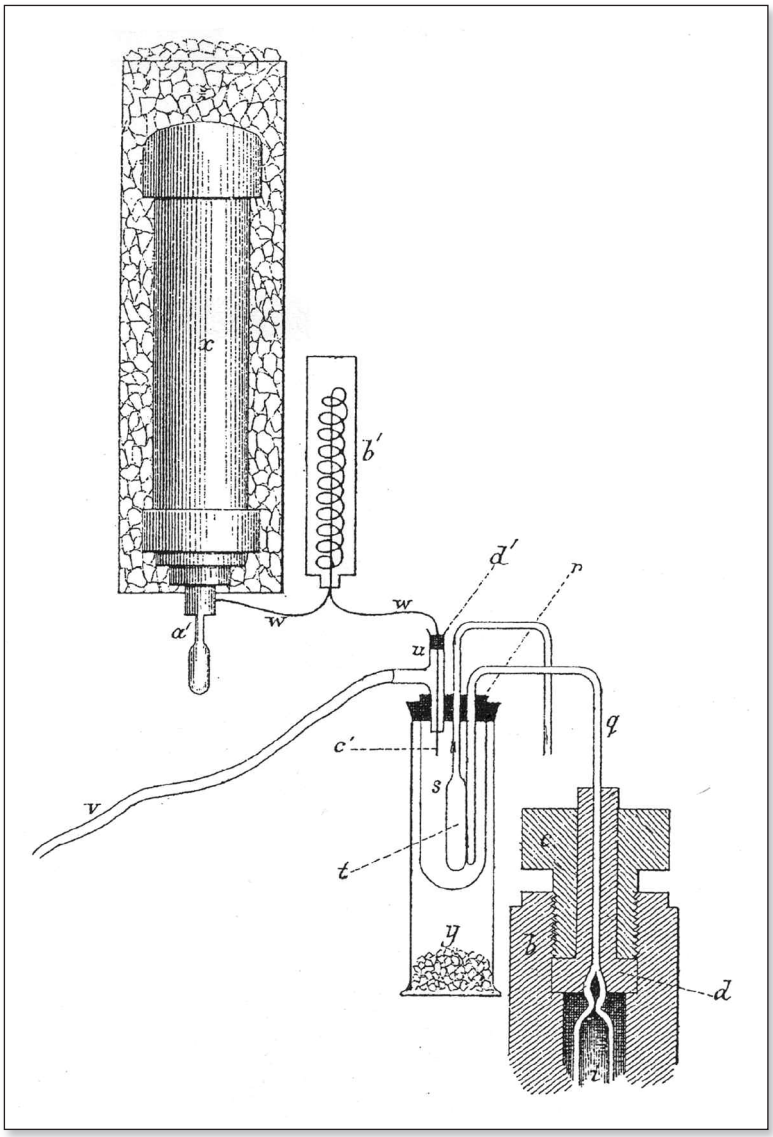
At the same meeting of the Academy a paper by Louis-Paul Cailletet announced a similar result. His approach consisted in applying huge pressures, followed by a sudden release. Without paying attention to the theoretical context–just like Pictet– he successively worked on acetylene, nitrogen dioxide, oxygen, and nitrogen. In all these cases he noticed not so much a liquid with a meniscus but a dense fog, that is, the 'dynamic' state as it was called, very close to the liquefaction point. Hydrogen was also tried out, but did not show any 'dynamics' if released at -28° and 300 atm. Later, however, 280 atm was sufficient to produce for a short while a very subtle mist. Cailletet's compression pumps and his manometers were wonders of the day.

Wróblewski and Olszewski: liquid oxygen in the *static* state (1883)

Cailletet's instrument, at the Ecole normale supérieure of Paris, had been studied carefully by at least one of his visitors: Zygmunt von Wróblewski. Upon returning to Poland, the latter brought with him an enlarged copy of it, made in Cailletet's workshop, and able to handle 200 cc of gas. Already in 1883 a first joint paper with Olszewski appeared: 'Ueber die Verflüssigung des Sauerstoffs, Stickstoffs und Kohlenoxyds', in *Wiedemann's Annalen der Physik* [1]. The gases were compressed by a force pump with mercury as an intermediate: the pump consisted of a piston in a barrel actuated by a screw which was driven by a huge wheel. Liquid ethylene, pre-cooled by a mixture of solid carbonic acid and ether, was used as a refrigerator. A hydrogen thermometer allowed one to follow the temperature (Figure 3).

The results were impressive: on April 4th, 1883, oxygen, for instance, showed up at -130 °C in a glass capillary tube as a colourless liquid [2] when the pressure was about 20 atm. By reducing the pressure it could be made to boil. This was, properly speaking, the real 'static' state. On a weekly base Wróblewski and Olszewski subsequently cabled their results to Paris where they appeared in the *Comptes Rendus* of the Academy. Oxygen was followed by nitrogen and carbon monoxide; hydrogen was next put on trial but did not give way, not even at -136 °C and 150 atm. The liquid oxygen, if it was indeed perceptible, could not yet be handled separately, however–let's say, poured from one flask into another– so there was still work to do.

By subtly varying the quantity of liquid Wróblewski and Olszewski were able to change its temperature. Indeed, when part of the liquid was above the boiling ethylene its temperature slightly rose and, with it, the pressure. At some point, the meniscus appeared to flatten and even to disappear. By lowering the mechanical pressure, the meniscus returned. Wróblewski–working alone now–noticed that the critical phenomena showed up at one particular pressure: about 50 atm. The critical temperature was far more difficult to determine. However, by adapting the pressure on the liquid ethylene its temperature could be made to vary



▲ **FIG. 3:** The refrigerating part of Wróblewski and Olszewski's liquefactor. The glass cylinder is closed with an airtight perforated rubber stopper, *r*, and contains calcium chloride, *y*, to eliminate water vapour. The round bottomed vessel *s* in it features the hydrogen thermometer *t*, the liquid ethylene inlet *c'* and the closed capillary with the oxygen, *q*. On the lower right the (modified) Cailletet compressor is shown only partly; i is the container with 200 cm^3 oxygen, to be compressed by a screw driven piston carrying mercury. The liquid ethylene is kept at *x* under and an ice-salt mixture (-20 °C); *a'* is a cock; it enters through a copper tube *ww*–partly spiralized to allow for further cooling by a 'Thilorier mixture' (ether and solid carbonic acid; *b'*)–fixed with a second stopper through a T-piece (*d'*). Tube *v* (lead) is linked to a vacuum pump, to make the ethylene boil at wish (lowest temperature attained -136 °C, at 2,5 cm Hg). Through the liquid ethylene the liquefied oxygen may be observed, if needed by using a beam of light (from ref. [1]).

▲ **FIG. 4:** The sealed flasks with argon (300 cm³) and helium (ca. 140 cm³) as sent by William Ramsay to Olszewski on 24 December 1894 and in July 1895, respectively.

considerably, which enabled one to follow the whereabouts of the meniscus. In this way, Wróblewski arrived at an estimate of -113 °C. Instead of the hydrogen thermometer a new, electric device was also tested (1885). It was a variant of the bolometer, based on the temperature dependency of the resistance of metals. In this context Wróblewski noticed that the resistance of copper in liquid nitrogen tended to zero. A sensational find, indeed, which made colleagues openly speculate on its potentialities. About 1886 and for unknown reasons Wróblewski changed the topic of his research. He tragically died, in his early forties, after a fire in the laboratory. Olszewski, already working on his own since late 1883, continued what came to be known as the Polish tradition in liquefaction.

Europe in the making: Ramsay and Olszewski (1895)

As is perfectly understandable in such a high-profile research domain, some rivalry arose, opposing Olszewski to James Dewar. Dewar had made fascinating discoveries on his own account, but tended to claim more than his fair share. It was the time that some *British* physicists openly complained about *British* colleagues who tended to deny honours due to foreigners. So it came, doubtless, that William Ramsay did *not* ask Dewar–working around the corner in London–to try to liquefy his newly discovered 'argon' and 'helium', but instead sent samples to Olszewski in Cracow (Figure 4). Argon did yield, indeed; it liquefied at -187,0 °C, solidified at -189,6 °C, with T_{crit} = -121 °C and p_{crit} = 50,6 atm [3]. Helium did not give way. ■

Acknowledgment:

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Henk Kubbinga is a historian of science at the University of Groningen and member of the EPS History of Physics Group. His new project concerns an annotated edition of *The collected papers of Frits Zernike (1888-1966)* and a *Biography* of Groningen's Nobel laureate.

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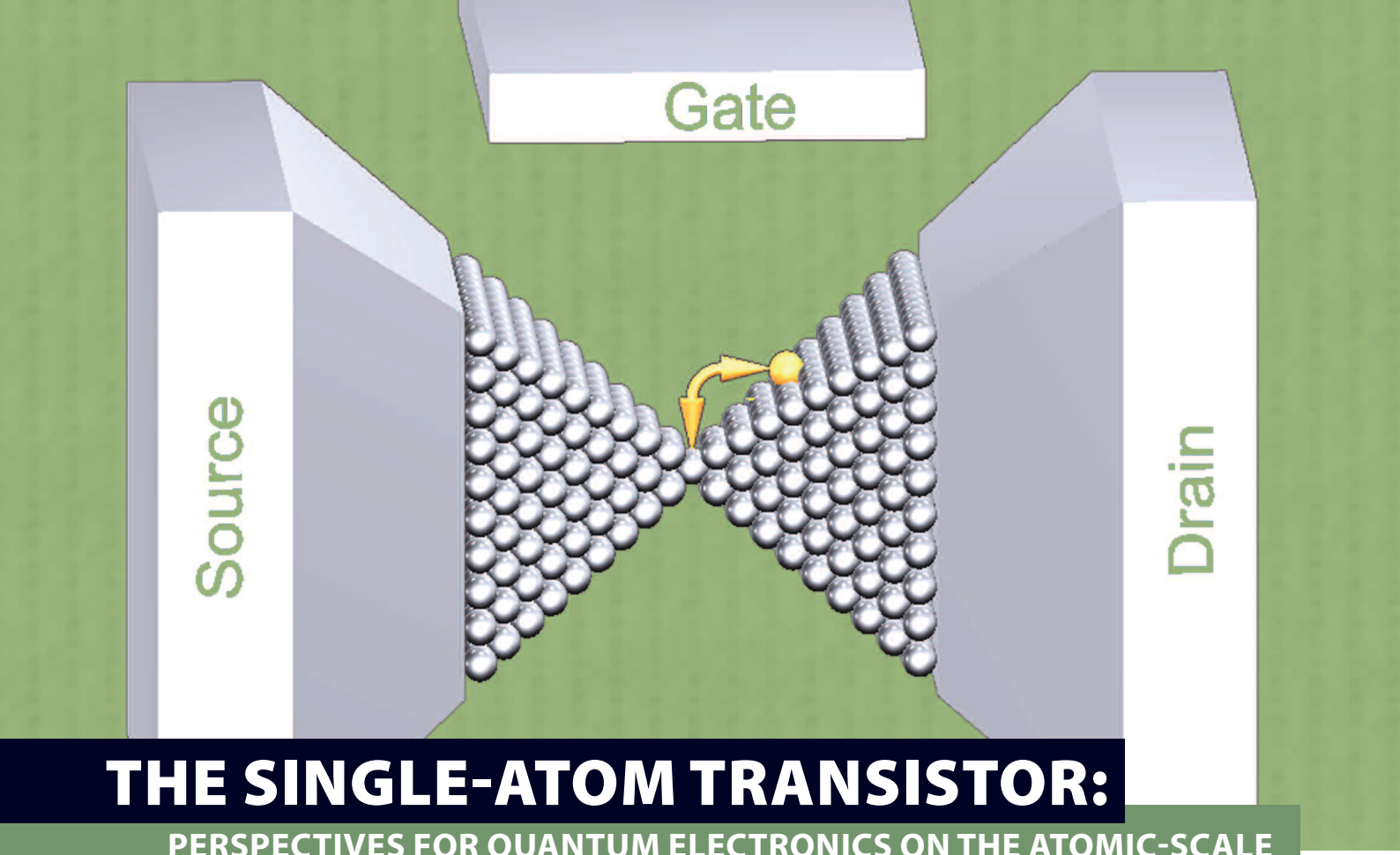

THE SINGLE-ATOM TRANSISTOR:

PERSPECTIVES FOR QUANTUM ELECTRONICS ON THE ATOMIC-SCALE

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Controlling the electronic conductivity on the quantum level will impact the development of future nanoscale electronic circuits with ultralow power consumption. Here we report about the invention of the single-atom transistor, a device which allows one to open and close an electronic circuit by the controlled and reproducible repositioning of one single atom. It opens intriguing perspectives for the emerging fields of quantum electronics and logics on the atomic scale.

Fascinating physical properties and technological perspectives have motivated investigation of atomic-scale metallic point contacts in recent years [1-10]. The quantum nature of the electron is directly observable in a size range where the width of the contacts is comparable to the Fermi wavelength of the electrons, and conductance is quantized in multiples of $2e^2/h$ for ballistic transport through ideal junctions [2].
In metallic point contacts, which have been fabricated by mechanically controlled deformation of thin metallic wires [2-4] and electrochemical fabrication techniques [1,5-7], the conductance depends on the chemical valence [2,3]. Two-terminal conductance-switching devices based on quantum point contacts were developed both with an STM-like setup [8] and with electrochemical methods [9]. In our new approach, a three-terminal, gate-controlled atomic quantum switch was fabricated by electrochemical deposition of silver between two nanoscale gold electrodes (see Fig. 1) [1,6]. A comparison of the experimental data with theoretical calculations indicates perfect atomic order within the contact area without volume or surface defects [10].

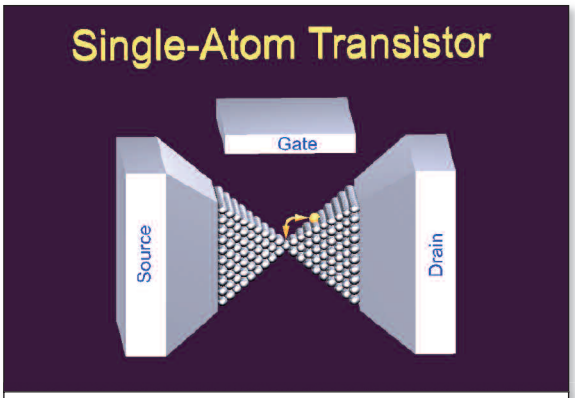
Switching an atom

We control individual atoms in the quantum point contact by a voltage applied to an independent gate electrode, which allows a reproducible switching of the contact between a quantized conducting "on-state" and an insulating "off-state" without any mechanical movement of an electrode (see Fig. 2).

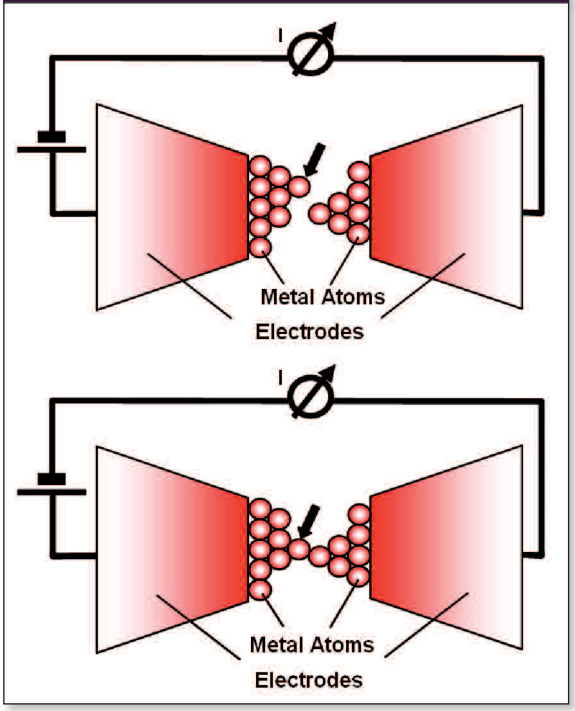
To fabricate the initial atomic-scale contact we deposit silver within a narrow gap between two macroscopic gold electrodes (gap width: typically 50 nm) by applying an electrochemical potential of 10-40 mV to a gate electrode [7]. The gold electrodes are covered with an insulating polymer coating except for the immediate contact area, and serve as electrochemical working electrodes. They correspond to the "source" and "drain" electrodes of the atomic-scale transistor. Two silver wires serve as counter and quasi-reference electrodes.

The potentials of the working electrodes with respect to the quasi-reference and counter electrodes are set by a computer-controlled bipotentiostat (see Fig.3). All experiments are performed at room temperature, the electrolyte being kept in ambient air. For conductance measurements, an additional voltage in the millivolt range is applied between the two gold electrodes. To fabricate the atomic transistor, silver is deposited on each of the two working electrodes, until finally two silver crystals meet, forming an atomic scale contact which is bridging the gap.

While silver islands are deposited in the junction we monitor the conductance between the two electrodes.



► **FIG. 1:** Schematic of the single-atom transistor: the atomic switch is entirely controlled by an independent third gate electrode, allowing to open and close a metallic contact between the source and drain electrodes by the gate-voltage-controlled relocation of one single silver atom.



► **FIG. 2:** Schematic of the switching process: A metal atom (see arrow) is switched between a quantized conducting "on-state" **(lower graph)** and an insulating "off-state" **(upper graph)**.

As soon as the conductance exceeds a preset "target" value, the deposition is stopped and the voltage is reversed to dissolve the junction again. After the conductance drops below a preset value, the deposition/dissolution cycle is repeated automatically by the computer-controlled setup. During the first cycles, the conductance at the end of the deposition step varies strongly from cycle to cycle [11]. After repeated cycling, an abrupt change is observed from this irregular variation to a bistable switching between zero and a finite, quantized conductance value at an integer multiple of G_0 (= $2e^2/h$).

Controlling the junction at the single-atom level

Figure 4 shows a sequence of reproducible switching events between an insulation "off-state" and a quantized conducting "on-state" (at 1 G_0), where the quantum conductance (red curves) of the switch is controlled by the gate potential (blue curves), as commonly observed in transistors. As calculations have shown [10], for atomic-scale silver contacts a quantized conducting "on-state" of 1 G_0 corresponds to a *single-atom* contact.

When we set the gate potential to an intermediate "hold" level between the "on" and the "off" potentials, the currently existing state of the atomic switch remains stable, and no further switching takes place. This is demonstrated in Fig. 5 both for the "on-state" of the switch (left arrow) and for the "off-state" of the switch (right arrow). Thus, the switch can be reproducibly operated by the use of three values of the gate potential for "switching on", "switching off" and "hold". These results give clear evidence of a hysteresis when switching between the two quantized states of the switch. It can be explained by an energy barrier which has to be overcome when performing the structural changes within the contact when switching from the conducting to the non-conducting state of the switch and vice versa.

The results indicate that switching occurs by a reversibly rearrangement of the contacting group of atoms between two different stable configurations with a potential barrier between them. For silver the observed quantum conductance levels appear to coincide with *integer* multiples of the conductance quantum [1,10].

The observed integer conductance levels of the switch are determined by the available bistable junction conformations, similar to the observation of preferential atomic configurations in metallic clusters corresponding to "magic numbers" [12]. By snapping into 'magic' bistable conformations, such energetically preferred junctions configurations are mechanically and thermally stable at room temperature, and they are reproducibly retained even during long sequences of switching cycles.

Mulitlevel switching

Reproducible switching in the above cases was always performed by opening and closing a quantum point contact, *i.e.* by switching between a quantized conducting state and a non-conducting state. However, it was not clear if this kind of gate-electrode controlled switching is also possible between two different conducting states of one and the same contact. Such kind of switching would involve two different stable contact configurations on the atomic scale, between which reversible switching would occur even without ever breaking the contact.

Such multi-level logics and storage devices on the atomic scale would be of great interest as they allow a more efficient data storage and processing with a smaller number of logical gates. By developing a modified procedure of fabrication, a multi-level atomic quantum transistor was obtained, allowing the gate-controlled switching between *different* conducting states.

Instead of setting the lower threshold where the dissolution process is stopped by the computer, to a value near 0 G_o, the lower threshold was set at a value above the desired quantized conductance of the lower of the two "on-state" levels [13].

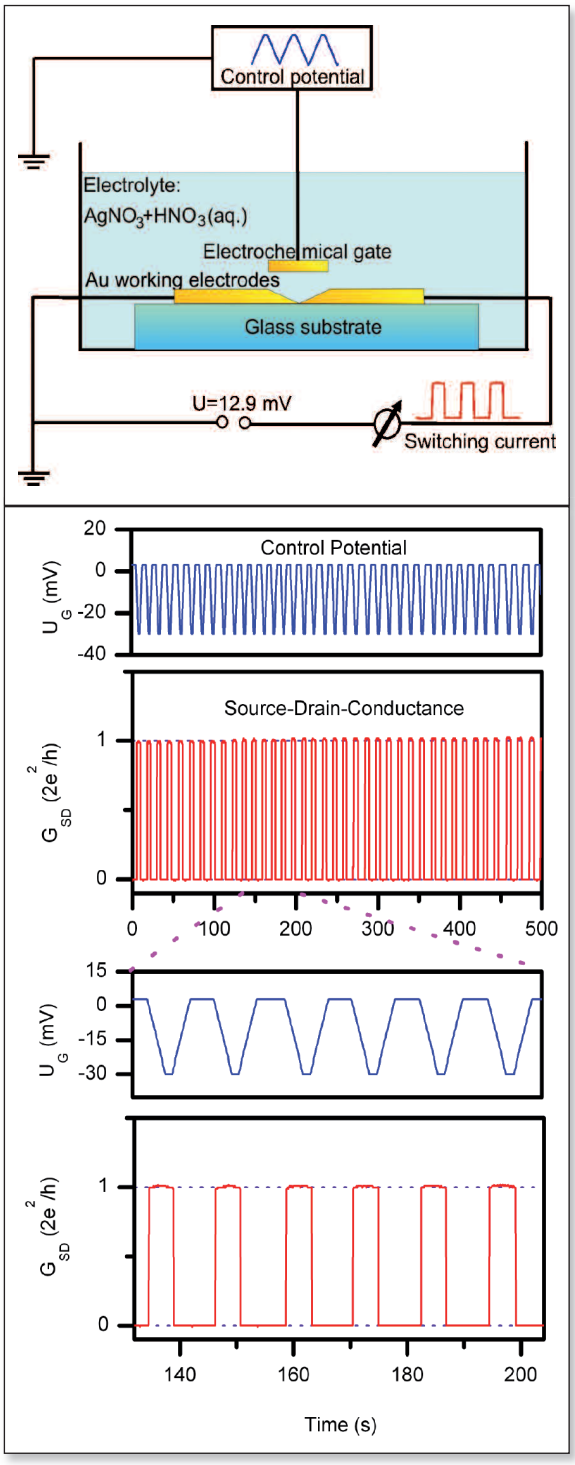
Figure 6 demonstrates the operation of such a two-level transistor: A controlled change of the gate potential U_G leads to a controlled switching of the conductance of the quantum point contact between two *different* quantized conducting states, exhibiting conductance levels of 1 G_0 and 3 G_0, respectively. Sharp transitions are observed between the two levels. No intermediate steps or staircase-like structures in conductance are observed in the diagram. The transitions are instantaneous within the time resolution of the diagram of Fig. 6 (50 ms).

Conclusions and perspectives

The development of the single-atom transistor represents a first demonstration of the functionality of a transistor on the atomic scale. This is of great interest, as there were many previous demonstrations of *passive devices* such as atomic-scale and molecular resistors. However, there was a lack of an *actively* switching device such as a transistor on the atomic scale. The atomic transistor as an actively controllable device, which reproducibly operates at room temperature, is filling this gap.

Atomic transistors represent a new class of devices which show remarkable properties:

- They allow the switching of an electrical current by the *geometrical relocation of individual atoms* rather than by locally changing electronic properties as done in conventional transistors.
- They represent quantum switches, the levels between which the switching occurs being given by fundamental laws of quantum mechanics.

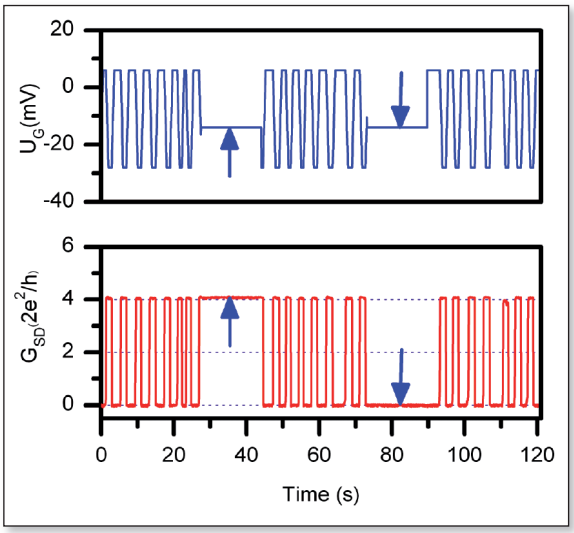


◀ **FIG. 3:** The experimental setup. Within a narrow gap between two gold electrodes on a glass substrate, a silver point contact is deposited electrochemically. By a procedure involving repeated computer-controlled electrochemical cycling, a bistable atomic-scale quantum conductance switch is fabricated.

◀ **FIG. 4:** Switching an electrical current by gate-controlled atomic movement: Experimental realization of reproducible electrical switching with a single silver atom point contact between an "on-state" at 1 G_0 (1 $G_0 = 2e^2/h$) and a non-conducting "off-state". The source-drain conductance (G_{SD}) of the atomic switch **(red curves)** is directly controlled by the gate potential (U_G) **(blue curves)**.

- They are a first demonstration of an *all-metal transistor* without the use of any semiconductor, the lack of a band gap allowing operation at very low voltages.

Such devices provide a number of advantages: They possess extremely nonlinear current-voltage characteristics, desirable in many applications, and they can be manufactured using conventional, abundant, inexpensive and non-toxic materials. At the same time, the devices open perspectives for electronic switching at ultrafast frequencies: although the switching time in our current investigations is limited by the response time of the electronic measuring setup (3-5 microseconds), the intrinsic

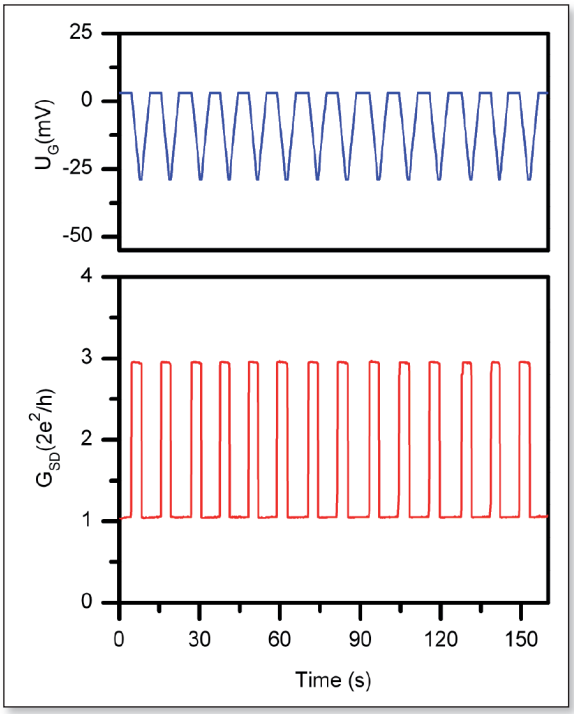


▶ FIG. 5: Demonstration of quantum conductance switching between a nonconducting "off-state" and a preselected quantized "on-state" at 4 G_0. A conductance level can be kept stable, if U_G is kept at a "hold" level (see arrows). (cf. [1]).

operation time is expected to be limited by the atomic-scale rearrangement within the junction (picoseconds), opening perspectives for ultra-high frequency operation. Because the switching process is achieved with very small gate potentials in the millivolt range, the power consumption of such devices is by orders of magnitude lower than that of conventional semiconductor-based electronics. Although the development of the single-atom transistor just marks the beginning of actively controlled electronics on the atomic scale, it opens fascinating perspectives for quantum electronics and logics based on individual atoms. The development of a first, simple integrated circuit [1,14] and a multilevel quantum transistor [13] are first encouraging steps in this direction.

Acknowledgment

We thank Robert Maul, Wolfgang Wenzel and Gerd Schön for stimulating discussions, for the excellent cooperation and for corresponding theoretical work. This work was supported by the DFG-Center for Functional Nanostructures and by the Baden-Württemberg Foundation within the Network of Excellence on Functional Nanostructures, Baden-Württemberg. ■



▶ FIG. 6: Example of a two-level quantum transistor switching between the conductance levels of 1 G_0 and 3 G_0, respectively. The source-drain conductance (G_{SD}) of the atomic switch (red curves) is directly controlled by the gate potential (U_G) (blue curves).

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PHYSICS IN DAILY LIFE:

MUDDY CYCLISTS

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When watching the *Tour de France* or the *Giro d'Italia* on a not-so-sunny day, we are confronted with a simple physics problem. Why is it that cyclists on a wet road tend to get their back decorated with a vertical stripe of mud? Of course, it is due to the water from the road picked up by the tire. Centrifugal forces throw it off the tire somewhere in the upper part of its trajectory, and the forward speed launches it towards the poor cyclist's back. But why does the water leave the tire somewhere around the highest point? A superficial analysis of the wheel's motion may give us a clue. Any point along the rim traces out a cycloid, and its speed varies from zero to twice the speed of the bike. So isn't the answer simply: it is because the speed of the tire rim is highest at its highest point, and so is the centrifugal force?

Reasonable as this may sound, it is entirely beside the point. Sure, it is the centrifugal force that counts. But that is the same everywhere along the wheel rim, given a certain speed. The fact that there is a linear motion superimposed on the wheel's rotation is irrelevant.

It is even quite the opposite, which we realize if we take gravity into account. Gravity tends to make the drops fall off much earlier, much closer to the road, whereas it tends to make the water stick to the tire near the top. We must conclude that the cyclist's back gets wet not *because of*, but *despite* the fact that the relevant tire part is near its highest position.

This raises the question: at exactly what speed does the cyclist get spattered with mud? We should realize that the drops leaving the tire precisely at its top position are rather innocent. They will leave horizontally, pass under the saddle and never make it to the cyclist's back. The real culprits are those drops that come off earlier, somewhere around 45 degrees before they reach the top, or even around 60 degrees before the top.

Now things get a bit complicated, since parameters like the exact position of the rider relative to the wheel come into play. Moreover, it is not sufficient to have centrifugal and gravitational forces balance. The water drops coming off the tire rim need some extra speed to be launched upward, in order to reach the cyclist's back.

A calculation for a standard cyclist and ignoring the drag on the droplets, done by Fokke Tuinstra from Delft University of Technology, shows that the drops which most likely make it to the rider's back will, indeed, leave the tire reasonably early, at around 60° before the top. They will hit the rider's back as soon as his speed exceeds some 12 km/h. If he rides a standard-size bicycle, that is. The reason is the crucial role of the wheel diameter. Given a certain speed v of the cyclist, the balance between centrifugal force and gravitation, $v^2/R = g$, shows that smaller wheels make things worse. So if you happen to be on your way to an important meeting wearing your business suit on a folding bike, you better make sure that the bike has an effective mudguard over its back wheel. ■

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KOREA INSTITUTE FOR ADVANCED STUDY (KIAS)

Research Fellow and Visiting Scholar Positions in Theoretical Physics

The School of Physics at Korea Institute for Advanced Study (KIAS) invites applicants for the positions at the level of postdoctoral research fellows and visiting scholars in theoretical physics.

Applicants for the research fellow position in theoretical physics are expected to have demonstrated exceptional research potential in the fields of *astrophysics & cosmology*, *particle physics & phenomenology*, *quantum field theory & string theory*, or *statistical physics & condensed matter theory*.

The starting date of the appointment is negotiable, and can be as early as March 2011. The initial appointment will be for two years with a possibility of renewal for up to two more years, depending on the research performance of an individual and also on the needs of the program at KIAS. The annual salary ranges from approximately US$ 29,000 ~ US$ 42,000 (equivalent to ₩32,000,000 ~ ₩46,000,000 in Korean currency). In addition, research fund in the amount of approximately US$ 6,400 ~ US$ 9,000 (equivalent to ₩7,000,000 ~ ₩10,000,000 in Korean currency) is provided each year.

Those interested are encouraged to contact a faculty member in their research areas at http://www.kias.re.kr/en/about/members.jsp. Also, for more information please visit http://www.kias.re.kr/en/notice/job_opportunity.jsp. Applicants should send a cover letter specifying the research area, a curriculum vita with a list of publications, and a summary of research plan, and arrange three recommendation letters to be sent to:

School of Physics:
Mr. Oh Beom Kwon (phys@kias.re.kr)
KIAS, 207-43 Cheongnyangni-dong
Dongdaemun-gu, Seoul, 130-722, Korea

Email applications are strongly encouraged. We accept applications all year round but the review of applications for the 2011 research fellow positions should be submitted by December 15, 2010 for full consideration.

The visiting scholar program is mainly for established scientists for short-term or long-term visits including sabbatical leaves. The successful candidates are expected to collaborate with research groups at KIAS. Collaborations with other visiting scholars or researchers in other institutions in Korea are also encouraged. Those interested should contact via e-mail one of the faculty members in the related field as a potential host. The appointment requires a curriculum vita with a list of publications and a summary of research plan.

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Physics research of world-class excellence and knowledge transfer to business and society. These are the key areas in which the Foundation for Fundamental Research on Matter (FOM) is focussing its efforts. Through taking a supportive and coordinating role, FOM is working on the future of physics research in the Netherlands. With funding from NWO, the national government and the European Union and with support from corporate sponsors, FOM develops and funds challenging research programmes and projects. FOM employs circa 980 people, comprised of some 85 permanent academic staff, 165 postdocs, 370 PhD students and over 360 technicians and other staff. The research is conducted in three institutes and some 150 university-based teams, spread over 11 Dutch universities. In total, staff produce approximately 80 PhD dissertations and 1300 scientific articles a year. FOM is part of the Netherlands Organization for Scientific Research NWO. More information on FOM is available at www.fom.nl.

Please do not contact this employer with services or other commercial interests.

FOM

In the coming years the Foundation for Fundamental Research on Matter (FOM) in the Netherlands will give a strong stimulus to fundamental energy research. As part of this initiative, the FOM-Institute for Plasma Physics 'Rijnhuizen' in Nieuwegein (200 employees) will be transformed into a **FOM-Institute for Fundamental Energy Research**, among others by starting two new energy research lines. The intention is to have the institute also play an important national coordinating role, by stimulating fundamental energy research and education in physics and related disciplines at Dutch universities and the institute, as well as by becoming the contact point in this area for external partners, such as industry or foreign research consortia. To make this possible, the institute will be relocated to the campus of the Technical University Eindhoven, and the institute will establish a number of `focus groups' at other universities and institutes in the Netherlands.

For this institute FOM is searching an energetic and ambitious new

Institute director

For this important position FOM is looking for a driven, preferably active, excellent scientist with management qualities; a born leader with passion for fundamental energy research and a stimulating personality who is able to bring people together and build bridges, someone with an open attitude both towards the employees of the institute, the FOM foundation, and external partners. The institute director is in charge of the daily operation of the institute, and has the vision and drive to lead the expansion and positioning of the institute and of the fundamental energy research agenda in the complex world of knowledge institutions, industry, politics and society. During the expansion and refocusing process of the institute the director will be assisted by two staff-members who will coordinate the relocation and move of the institute, so that the director will have ample time for establishing the new research directions of the institute and, if desired, for building up his or her own research group.

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Please send your application letter with curriculum vitae no later than August 22 2010 to
R.A. Koornstra LLM
FOM Foundation
P.O. Box 3021, 3502 GA Utrecht,
The Netherlands
or by email to energydirector@fom.nl.

For information or in order to bring suitable candidates to the attention of the search committee, please contact the FOM Director, Dr. W. van Saarloos.

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