swiss physical society

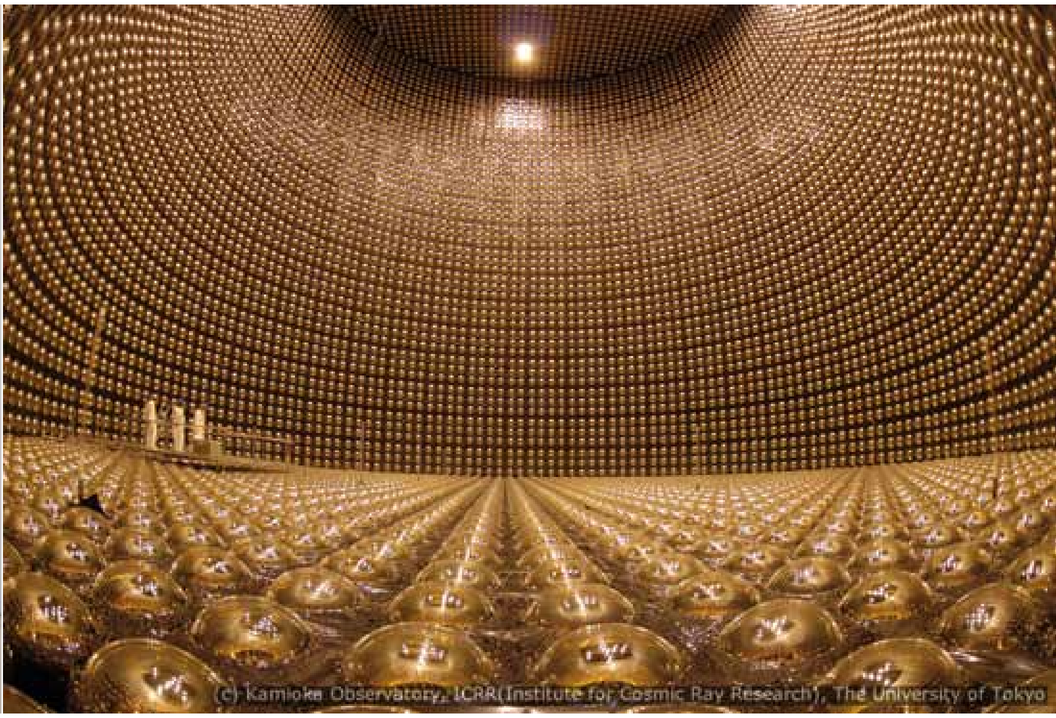
Nr. 47
November 2015

SPG MITTEILUNGEN
COMMUNICATIONS DE LA SSP

The award winners 2015 of SPS and ÖPG. Photo: A. M. Andrews and H. Detz, TU Wien

Prof. Herwig Schopper, new Honorary Member of the SPS, receives his diploma from Prof. Felicitas Pauss, (CERN) See p. 14.

The Einstein house in Bern is the first EPS-APS Historic site (see page 46).



Inside view of the Superkamiokande detector during final installation of the 11,146 photomultipliers (PMTs), which led to the discovery of neutrino oscillations, awarded with this year's Nobel Prize. Read more on p. 33.

From Kamioka Observatory, ICRR, University of Tokyo.

Inhalt - Contenu - Contents

Editorial 3
The winners of the SPS Awards 2015 4
Review of the Joint Annual Meeting 2015 in Vienna 7
    epl Journal Poster Award Wien 2015 13
    Short report on SPS General Assembly in Wien, 2. September 2015 14
    New SPS Committee Members 15
Neuer SPG-Preis für Arbeiten auf dem Gebiet der computergestützten Physik -
    Nouveau prix de la SSP pour des travaux dans le domaine de la physique numérique 16
New Series "Plenary Talks" 16
Progress in Physics (50): Formation of rogue waves under forcing fields 26
Progress in Physics (51): Will ultracold neutrons reveal their electric dipole moment? 29
The 2015 Nobel Prize in Physics 33
European Energy Policy and Global Reduction of CO_2 emissions: Towards an effective sustainable electricity production in Europe 36
History of Physics (14): Recollections of Max Born 38
Jost Bürgis genialer Artificium-Kunstweg entdeckt 44
Joint EPS-APS Historic Site "Einstein House" 46
PiA - Physics in Advent 47
Emmy Nöther Distinction for Anna Fontcuberta i Morral 48
Kurzmitteilungen - Short Announcements 49
Ausschreibung der SPG Preise für 2016 - Annonce des prix de la SSP pour 2016 51

Vorstandsmitglieder der SPG - Membres du Comité de la SSP

SPG Administration - Administration de la SSP

Allgemeines Sekretariat - Secrétariat générale
(Mitgliederverwaltung, Webseite, Druck, Versand, Redaktion Bulletin & SPG Mitteilungen) - (Service des membres, internet, impression, envoi, rédaction Bulletin & Communications de la SSP)
S. Albietz, SPG Sekretariat, Departement Physik,
Klingelbergstrasse 82, CH-4056 Basel
Tel. 061 / 267 36 86, Fax 061 / 267 37 84, sps@unibas.ch

Buchhaltung - Service de la comptabilité
F. Erkadoo, francois.erkadoo@unibas.ch

Protokollführerin - Greffière
Edith Grüter, edith.grueter@epfl.ch

Wissenschaftlicher Redakteur - Rédacteur scientifique
Dr. Bernhard Braunecker, Braunecker Engineering GmbH, braunecker@bluewin.ch

Impressum:

Die SPG Mitteilungen erscheinen ca. 2-4 mal jährlich und werden an alle Mitglieder abgegeben.

Abonnement für Nichtmitglieder:
CHF 20.- pro Jahrgang (Inland; Ausland auf Anfrage), incl. Lieferung der Hefte sofort nach Erscheinen frei Haus. Bestellungen bzw. Kündigungen jeweils zum Jahresende senden Sie bitte formlos an folgende Adresse:

Verlag und Redaktion:
Schweizerische Physikalische Gesellschaft, Klingelbergstr. 82, CH-4056 Basel, sps@unibas.ch, www.sps.ch

Redaktionelle Beiträge und Inserate sind willkommen, bitte wenden Sie sich an die obige Adresse.
Namentlich gekennzeichnete Beiträge geben grundsätzlich die Meinungen der betreffenden Autoren wieder. Die SPG übernimmt hierfür keine Verantwortung.

Druck:
Werner Druck & Medien AG, Kanonengasse 32, 4001 Basel

sc | nat
Member of the Swiss Academy of Sciences

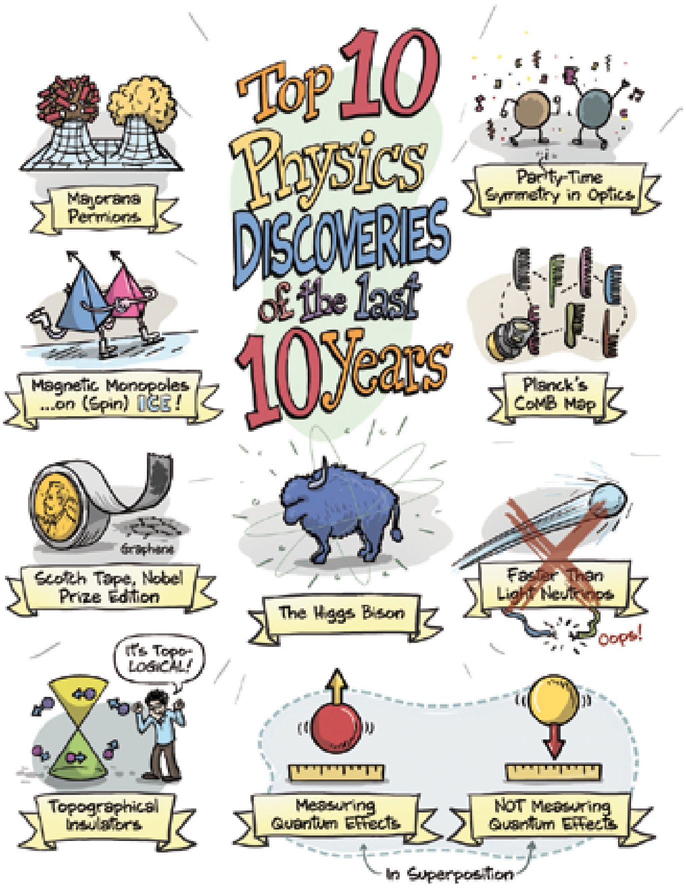
SATW
Schweizerische Akademie der Technischen Wissenschaften
Académie suisse des sciences techniques
Accademia svizzera delle scienze tecniche
Swiss Academy of Engineering Sciences

Editorial

It is the material, stupid!

Christian Rüegg, PSI Villigen und Uni Genève, SPS Section Condensed Matter

It is the time of the year when many rankings are published – of universities, major breakthroughs in science, and top 10 physics discoveries [1], among many others. Serious or not, they reflect our very human desire to measure things, to feel part of an elite group (or not), or to make smart-sounding small-talk at our next physicist party. If we don't care too much about who or what comes first, they are simple lists of great achievements. For condensed matter physics, it would be easy to compile quite a long list of major discoveries made during just the last decade. Again with no order of importance or impact, and with no ambition to be complete, I would add to any such list the discovery of new iron-based superconductors and of topological insulators with the related Weyl and Majorana fermions.



These two important and recent discoveries have a few aspects in common and yet are very different in many others. On the materials and experimental side, both profited directly from progress in materials synthesis, nano-processing and instrumentation that were refined over decades, for example by performing experiments on superconducting cuprates, on semiconductors, and in mesoscopic physics. On the other hand, theory and ab-initio computational methods were clearly ahead of experiment for topological effects in solids, whereas it still proves to be very challenging to predict the superconducting properties of materials beyond standard BCS theory. Thus the culmination of our expertise in the synthesis of high-quality single crystals of semiconductors, the control of their magnetic and electronic properties via doping, and the design and engineering of band structures have allowed us to realize new types of topological electronic state in solids by following specific instructions. But we still do not understand why some materials superconduct at surprisingly high transition temperatures.

The example of topological insulators and recent work in my field of quantum critical matter make me quite confident that, in some areas of condensed matter physics, computational methods will play a leading role and guide experimentalists towards the 'right' interesting materials, both for fundamental studies and for more applied functionalities in future devices. In Switzerland, the new NCCR MARVEL, a National Centre of Competence in Research for computational design and discovery of novel materials, led by EPF Lausanne, is a major initiative in this direction. It is in good international company, for example with the Materials Genome and further privately funded projects in the US.

So, why do we still need materials discovery and synthesis in a chemistry lab driven by curiosity, intuition and experience? My personal answer is that we actually need much more of this in Switzerland. In fact we only understand relatively simple semi- and superconductors from first principles, and well enough to model their properties and device functionalities on a computer. This know-how was developed largely over decades of close interaction between experimental and computational groups, which have constantly been challenged by intriguing discoveries in new compounds and heterostructures. In particular, it was on surfaces and at interfaces where very interesting new effects were discovered recently, such as superconductivity at the interface of two insulators, or in systems with a subtle competition between energy scales, and this makes it even more challenging to predict emergent phenomena. In all of these cases, new experimental probes providing enhanced sensitivity and new, complementary information have helped to solve the puzzle and to guide calculations in new directions. In Switzerland we have been investing constantly in such new instrumentation, for example at the Paul Scherrer Institute and at complementary European facilities, and we should continue to do so.

My preliminary conclusion is that right now it would be a mistake to leave materials design and discovery to computers, or restrict ourselves to combining and processing materials that we already know – we need more groups actually making them. The biggest gains I see happen in close 'interdisciplinary' collaborations between groups in materials synthesis, computational and experimental physics, and nanotechnology, which produce and study the materials we need now and in the future. The NCCR MARVEL is an important step in this direction and we may need further Swiss initiatives, which combine all of this expertise under the same roof.

[1] Top 10 Physics Discoveries of the Last 10 Years, Jorge Cham, Nature Physics **11**, 799 (2015).

The winners of the SPS Awards 2015

The SPS Award committee under the lead of Professor Louis Schlapbach selected the winners for 2015 out of numerous submissions. Their work was presented at the annual meeting in Vienna. Please find in the following the laudationes written by Louis Schlapbach and the summaries written by the authors.

SPS Award in General Physics, sponsored by ABB

The SPS 2015 Prize in General Physics is awarded to **Gregor Jotzu**, for his excellent PhD-work on the "*Experimental realization of the topological Haldane model with ultracold fermions*" (*Nature*, **515**, 237–240; 2014), which is at the intersection between quantum optics and solid-state physics.

He realized a singular advance towards the long-standing goal of exploring topological phases of matter using ultracold atomic gases, by establishing and demonstrating the necessary methodology both to prepare and to probe cold atoms in topological bands. The platform he developed, based on fermionic potassium atoms, opens up the possibility of using ultracold atomic gases to explore novel *strongly correlated* topological phases. This new approach is of great significance beyond the realm of cold atoms — it is of direct relevance to current research in solid-state physics, for example on topological insulators, and might well lead to surprising insights into topological properties of matter.

Experimental realisation of the topological Haldane model with ultracold fermions

Just like surfaces such as a sphere or a torus can be assigned to distinct topological classes, the wave-function of electrons in a solid may also be characterised by its topological properties. In 1988, F.D.M. Haldane proposed the Hamiltonian for a material which could intrinsically feature non-trivial topological properties [1]. Although physical implementation has been considered unlikely, Haldane's model has provided the conceptual basis for theoretical and experimental research exploring topological insulators and superconductors. Using ultracold fermionic atoms in a periodically modulated honeycomb optical lattice, we have experimentally realized Hadane's model as a Floquet Hamiltonian [2]. Such Hamiltonians can be used to describe the behaviour of a periodically modulated system on longer time-scales. They may contain novel features not present in the original system. Using circular modulation of a honeycomb lattice, we hence induce complex next-nearest-neighbour tunnelling terms, which break time-reversal symmetry - a crucial ingredient for Haldane's model. In addition, inversion symmetry is broken by introducing an energy offset between neighbouring sites. Breaking either of these symmetries opens a gap in the band structure, which we probe using momentum-resolved interband transitions. We explore the resulting Berry curvatures, which characterize the topology of the lowest band, by applying a constant force to the atoms and find orthogonal drifts analogous to a Hall current. The competition between the two broken symmetries gives rise to a transition between topologically distinct regimes. By identifying the vanishing gap at a single Dirac point, we map out this transition line experimentally. We verify that our approach is suitable even for interacting fermionic systems, allowing for future studies of the interplay of topological bands and magnetism or superfluidity.

[1] F. D. M. Haldane. Physical Review Letters 61, 2015 (1988)
[2] G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, and T. Esslinger. Nature 515, 237-240 (2014)

SPS Award in Condensed Matter Physics, sponsored by IBM

The SPS 2015 Prize in Condensed Matter Physics is shared between **Simon Gerber** and **Bastien Dalla Piazza**.

Simon Gerber receives the award for his excellent PhD work that lead to the remarkable identification of a novel exotic quantum phase in $CeCoIn_5$. This novel phase features the direct coupling of unconventional superconductivity of d- and p- wave symmetry to a spin-density wave. This makes this material a truly exceptional example of an exotic quantum phase that is of general importance for physics.

For his experimental work, Simon Gerber used a combination of high-magnetic field neutron diffraction - close to the upper critical field of $CeCoIn_5$ - together with a specially designed and constructed attocube piezo goniometer. His findings allow to identify the Q-phase as a novel quantum phase where d-wave and p-wave superconductivity combine into a novel Cooper pair density wave that couples to a spin density wave. The results were published as "*Switching of magnetic domains reveals spatially inhomogeneous superconductivity"* in *Nature Physics* **10**, 126 (2014).

Bastien Dalla Piazza receives the award for his outstanding PhD work on the fundamental understanding of the excitation spectrum in the two-dimensional quantum antiferromagnet - which is among the most fundamental models in quantum many body theory.

Switching of magnetic domains reveals spatially inhomogeneous superconductivity

The cerium 115 heavy-fermions represent a prototypical material family to study the interdependence of quantum phases due to strong electron correlations. In particular, $CeCoIn_5$ has been at the focus of intense research activity and serves a model material for studies of unconventional superconductivity in the proximity of magnetism. Using high-field neutron scattering we have shown that a long-range ordered, incommensurate spin-density wave (SDW) emerges in a continuous quantum phase transition inside the, so-called, superconducting Q-phase [1]. Both the superconducting and the SDW order parameters then break down simultaneously at the upper critical field, suggesting a direct coupling between magnetism and superconductivity. Furthermore, we find that always only one of two possible SDW domains is populated in the Q-phase, which however cannot be explained by magnetic spin anisotropies. Carefully rotating the magnetic field direction allows for direct control and hypersensitive switching of the domain population. This sharp and binary switching behavior provides strong evidence that the Q-phase in $CeCoIn_5$ is governed by a tri-linear coupling term of singlet d-wave superconductivity, incommensurate SDW order and a spatially inhomogeneous triplet p-wave Cooper pair-density wave, forming a complex quantum state that can be sensitively manipulated via the control parameter of the respective quantum phase transition.

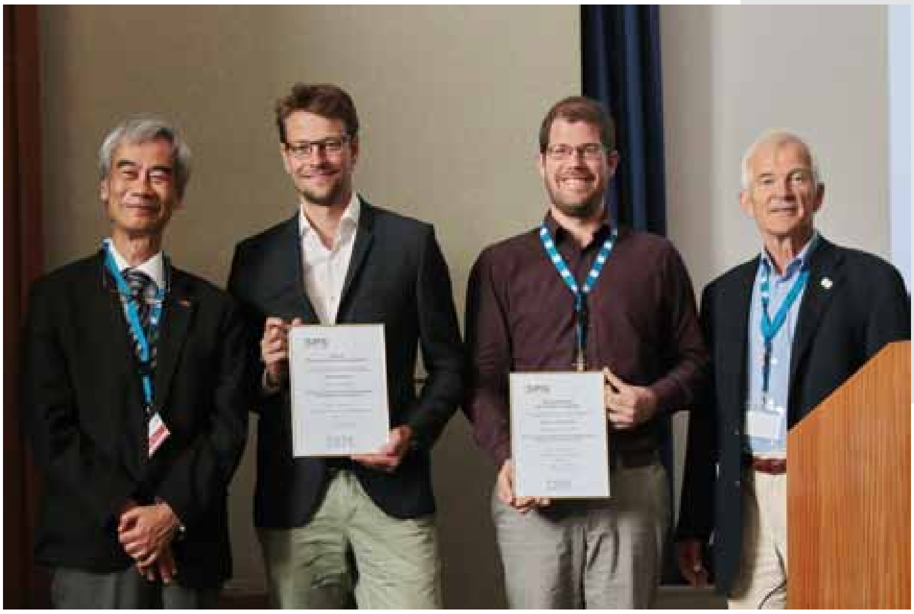
[1] S. Gerber, M. Bartkowiak, J. L. Gavilano, E. Ressouche, N. Egetenmeyer, C. Niedermayer, A. D. Bianchi, R. Movshovich, E. D. Bauer, J. D. Thompson, and M. Kenzelmann, Nature Physics 10, 126 (2014).

Bastien Dalla Piazza created a theoretical approach based on variational wave-function Monte-Carlo, providing the best description to date of the dynamics in the model. He was able to demonstrate that the high-energy excitations are fractional "spinons" – a phenomenon normally associated with one-dimensional systems. The results were published as "*Fractional excitations in the square lattice quantum antiferromagnet*" in *Nature Physics* **11**, 62-68 (2015).

Fractional excitations in the square lattice quantum antiferromagnet.

While quantum mechanics underlies all the macroscopic physics that forms our reality, it rarely manifests itself explicitly at that scale. From that observation follows the traditional view that quantum mechanics becomes most relevant for infinitesimally small systems. However strong quantum effects at macroscopic scales do exist and the keys for this are dimensionality and many- body interactions. In the quantum magnetism field, these key elements are best studied in the corner stone model: the Heisenberg model. It describes quantum magnetic moments interacting together on a lattice and its parameters are the lattice topology and the form of the interaction. In a three- dimensional cubic lattice for instance, the physics is dominantly classical with long range magnetic order only slightly renormalized by quantum effects. In contrast in a one-dimensional spin-chain, the quantum effects dominate causing the magnetic system to lie in a disordered quantum spin- liquid state. A salient property of such systems is the emergence of quasi-particles excitations -- spinons in this particular case -- that are only fractions of those found in vacuum or, equivalently, those found in the non-interacting limit. Between these two cases lies the two-dimensional square lattice studied here. The system has long-range order strongly renormalized by quantum effects and low-energy/long wavelength excitations are fluctuations of the magnetic order called spin waves, similar to phonons in solids. However recent experimental work [1] evidenced strong deviations from the spin-wave predictions in the high-energy/short wavelength regime. In recent work, we showed that these deviations are compatible with a model where spin-waves fractionalize into pairs of spin-1/2 quasi-particles [2] not unlike those found in one-dimensional systems.

[1] Quantum dynamics and entanglement of spins on a square lattice, N. B. Christensen, et al., Proceedings of the National Academy of Sciences 104 15264–15269 (2007)
[2] Fractional excitations in the square lattice quantum antiferromagnet, B. Dalla Piazza et al., Nature Physics 11, 62-68 (2015)



From left to right: Minh Quang Tran, SPS President, Simon Gerber, Bastien Dalla Piazza, Louis Schlapbach, President of the SPS Award Committee.

All photos in this article: Antoine Weis, Uni Fribourg

SPS Award in Applied Physics, sponsored by OC Oerlikon

Branimir Radisavljevic is awarded with the SPS 2015 Prize in Applied Physics for his exploring PhD studies of the electronic properties of monolayered transition-metal dichalcogenide - single-layer MoS_2 - published as "*Mobility engineering and metal-insulator transition in monolayer MoS_2*" (*Nature Materials*, **12**, p. 815, 2013) and "*Single-layer MoS_2 transistors*" (*Nature Nanotechnology*, **6**, p. 147, 2011). He demonstrated the first transistors and integrated circuits with characteristics that outperform graphene electronics in many aspects and have comparable properties to nowadays silicon electronics.

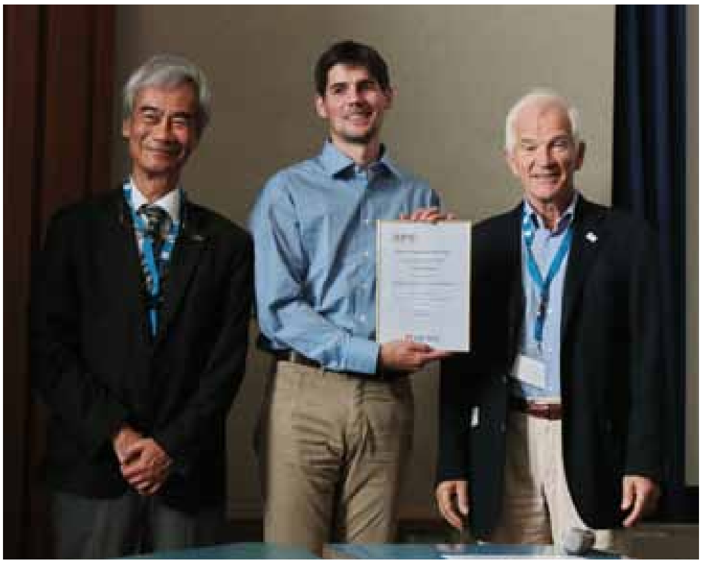
Single-layer MoS_2: Electronics in two dimensions

On this project we were confident that by proper substrate and dielectric engineering and by better electrostatic control of the single-layer MoS_2 channel, carrier mobility, current on/off ratio and subtreshold swing in field-effect transistors can be improved enough to become at least close to state-of-the-art semiconductor technology. In fact, any potential replacement of silicon in CMOS-like digital logic devices is desired to have a current on/off ratio Ion/Ioff between 10^4 and 10^7 and a band gap exceeding 400 meV. For the first time high current on/off ratio ~10^8, subtreshold swing as low as 74 mV/dec and moderately high electron mobility ~50 cm^2/Vs are demonstrated in any two-dimensional semiconducting material [1].
Subsequently, based on this platform we fabricated and demonstrated operations of the first logic gates, integrated circuits [2] and small-signal analog amplifiers which paved the way for two-dimensional semiconducting materials based flexible electronics, and resulted in MoS_2 being included in the semiconductor industry ITRS roadmap.
The encapsulation of monolayer MoS_2 in a high-κ dielectric environment was shown to result in an increase of the room-temperature mobility as we have demonstrated in our previous publications. In a follow-up work [3] we showed by cryogenic and Hall-effect measurements that the main reason for this increase was reduced Coulomb scattering due to the high-κ dielectric environment and possible modification of phonon dispersion in MoS_2 monolayers. An increase of mobility with the dielectric deposition, similar to that in monolayers was also observed in multilayer samples and monolayer samples with polymer gating. Additionally, for the first time, we observed metal-insulator transition in one two-dimensional semiconducting material, which is explained by strong electron-electron interactions. This transition point is in very good agreement with theory and shows that monolayer MoS_2 could be an interesting new material system for investigating low-dimensional correlated electron behavior.

[1] B. Radisavljevic, et al., "Single-layer MoS_2 transistors," Nature Nanotechnology, 2011.
[2] B. Radisavljevic, et al., "Integrated Circuits and Logic Operations Based on Single-Layer MoS_2," ACS Nano, 2011.
[3] B. Radisavljevic and A. Kis, "Mobility engineering and a metal–insulator transition in monolayer MoS_2," Nature Materials, 2013.

SPS Award related to Metrology, sponsored by METAS

The SPS 2015 Prize related to Metrology is awarded to **Peter Rickhaus** for his excellent PhD-work on unique steps on the way to graphene based ballistic electron optics and electronic devices, published as "*Ballistic interferences in suspended graphene*" (*Nature Communications* **4**, 2342 (2013)) and "*Snake Trajectories in Ultraclean Graphene p-n Junctions*" (*Nature Communications* **6**, 6470 (2015)).
Peter Rickhaus successfully demonstrated how to increase charge transport mobilities in graphene by three orders auf magnitude to 1'000'000 cm^2/Vs - yielding a mean free path in the μm range - using in-situ current annealing techniques of suspended graphene. With these clean materials he realized ballistic p-n junctions demonstrating Fabry-Perot interference oscillations known from optical cavities. Guiding of the electrons was achieved when a p-n junction was combined with a small perpendicular magnetic field. The semi metallic nature and bipolarity of monolayer graphene has made it possible to generate guiding with the aid of a constant magnetic field for the first time.



Electron-Optics in suspended Graphene

In ballistic graphene, electrons behave in many ways similar to photons. By changing the electrostatic potential locally, we realized elements in graphene that are known from optics. But in contrast to conventional optics, gapless p-n interfaces can be formed in graphene showing a negative index of refraction and the effect of Klein tunneling. The electron-optics devices that we studied were fabricated using high-mobility suspended monolayer graphene on organic lift-off resists. Recently we demonstrated that with this technique a ballistic p-n junction can e formed representing a Fabry-Pérot etalon. We further studied the transition from the Fabry-Pérot to the Quantum Hall regime of such a p-n interface under perpendicular magnetic field. Striking features appear that can be traced to the formation of "snake states" along the p-n interface [2]. By this electrons can be guided already at very small magnetic fields of 100 mT. Beyond that we demonstrated that electrons in ballistic graphene can be guided by gate potentials the same way as photons in an optical fiber, and that the formation of a p-n interface increases the guiding efficiency due to Klein filtering. We showed that we can fill the electrostatic guiding channel mode by mode.

[1] P. Rickhaus, R. Maurand, Ming-Hao Liu et al., Nature Comm. 4, 2342 (2013)
[2] P. Rickhaus, P. Makk, Ming-Hao Liu et al., Nature Comm. 6, 6470 (2015)

Review of the Joint Annual Meeting 2015 in Vienna

Every two years, the Annual Meeting of the Swiss Physical Society is organised jointly with our colleagues of the Austrian Physical Society (ÖPG) and the Swiss and Austrian Societies of Astronomy and Astrophysics (ÖGAA, SSAA). The joint meeting takes place alternatively in Switzerland and Austria, but on the occasion of the 200th anniversary of the "Technische Universität Wien", we came two times in a row to Austria, this time to the great city of Vienna.

In total, there were about 470 participants with about 350 contributions, of which there were a good 250 specialized oral contributions and almost 100 posters. The Swiss participation amounted to 25 %.
Since experimental physics needs technologies, we had, as usual, also a scientific exhibition with 18 companies presenting their products for labs and libraries...

What is very pleasant with national meetings, in contrast to international specialized meetings, is that they present the rare possibility of listening to other fields of physics, a way to follow their development. We could effectively listen to 11 plenary talks covering all the domains of physics in the morning sessions, and to 2 evening public lectures meant for a large public – although these were sometimes quite smart talks.

Specialized sessions, with invited and contributed talks, occupied the afternoons and gave again the voice to everyone's specialized domain. Such a conference is also the place for some major big experiments to gather their members, holding full sessions on their apparatus. Often these domain sessions give the opportunity for young PhD students to perform their first presentation outside their laboratory and play thus an important role as training in the start of a career. To underline this educational role, a poster prize has been offered here as a good stimulus to promote quality in results and efficient communication (p. 13).

Quality works from young physicists were recognized in four different domains with the renowned SPS Awards (p. 4), going to be five next year (see p. 16). We had also the pleasure to distinguish this year a new honorary member in the person of Herwig Schopper (p. 14).

The conference itself was preceded by a one-day gathering on the theme of energy, the "Energietag", organized by the "Arbeitskreis Energie" (AKE) of the Austrian Physical Society, an event of concern in today's context.

Among the good moments of the conference, let us not forget the conference dinner at the "Schreiberhaus", a colourful "Heurigen" restaurant of which our Austrian friends are proud, with accordion music and their staff in traditional costumes. Heurigen remembers them at the time of the empire when certain peasants or wine growers did not have to pay taxes if the goods were sold on place, a little character of exception which makes them smile.

Such a conference also allows to further build up networks with people of the different domains represented, an activity that reveals useful when later in search of data in a domain or of an adequate speaker for a specialized talk. Or for talks at gymnasial, student or PhD student level, or for summer or winter schools, teacher events, various trainings… It also becomes the place to think about the relation of science with society in a large sense, as an example here about the energy issue, playing the role of a scientific platform for such debate.

In general, multi-domain conferences of this kind are essential and complementary to highly specialized international conferences, both having their specific reason of existing. Their simultaneous existence establishes a good equilibrium between the need at the same time of specialization and broad physics basis.

Prof. Gottfried Strasser, head of the local organising team, was very happy with the success of this 4th edition of our joint ÖPG-SPS annual meeting when closing the conference.

In a single sentence, a very enjoyable meeting both from a scientific and cultural point of view. The only regret: science took precedence and the richness of the Viennese culture and monuments has suffered!

Antoine Pochelon and Minh Quang Tran

The following articles are short summaries of the sessions, written by the section heads.

Energietag – Energy day

The Energy day ("Energietag") is a one-day event by the "Arbeitskreis Energie" of the Austrian Physical Society. It has taken place one day before the annual meeting for the last few years. This time it was organized together with the Swiss Physical Society for the first time. Under the topic "Temperature differences as energy sources", different aspects of using low-grade temperature differences and their limitations were presented.

In a first part thermoelectricity as a way to convert temperature differences into electric power was discussed. Karl-Heinz Gresslehner gave an introduction into the foundations of thermoelectricity and how different material properties have to be balanced to reach high efficiencies. Silke Bühler-Paschen showed how these material properties can be influenced by structuring the material e.g. in order to separate electrical and thermal conductivity. Ernst Bauer discussed applications of thermoelectricity in industrial applications and the automobile industry but also for autonomous sensor systems.

This year's plenary speakers (from left to right): Thomas Müller (TU Wien), Georg Kresse (Uni Wien), Joël Mesot (PSI Villigen), Gijs Wuite (Uni Amsterdam), Klaus Kirch (ETH Zürich & PSI Villigen), ...

Susanna Zapreva showed how the changes in energy production towards renewable energies change the utilities. Her company had to develop completely new offerings for their customers in order to cope with the expectations of consumers.

Two talks presented different aspects of energy storage. Jaroslav Hemrle discussed a project on electrothermal energy storage on a large scale. He pointed out that a highly optimized system is necessary in order to be profitable with such a system. Andreas Werner presented his work on electrochemical energy storage. They are searching for efficient reversible chemical reaction systems and ways to implement them in industrial systems.
The use of high-temperature heat pumps as a way to make efficient use of waste heat was finally presented by Thomas Fleckl, an area were new systems are currently developed and released.
In a public evening lecture Reinhold W. Lang presented the role of plastics within a sustainable (energy) future.

Kai Hencken

Condensed Matter (KOND)

Recent highlights in condensed matter and surface and interface physics were presented in 9 sessions with a large number of invited and contributed talks and during the poster session. Especially the presentations of the various SPS award winners were of exceptional quality covering important current topics like unconventional superconductivity (Gerber), quantum magnetism (Dalla Piazza), and novel materials for future electronics (Radisavljevic and Rickhaus). The speakers of two presentations given to the plenary audience identified two important, but very different future directions in condensed matter research.

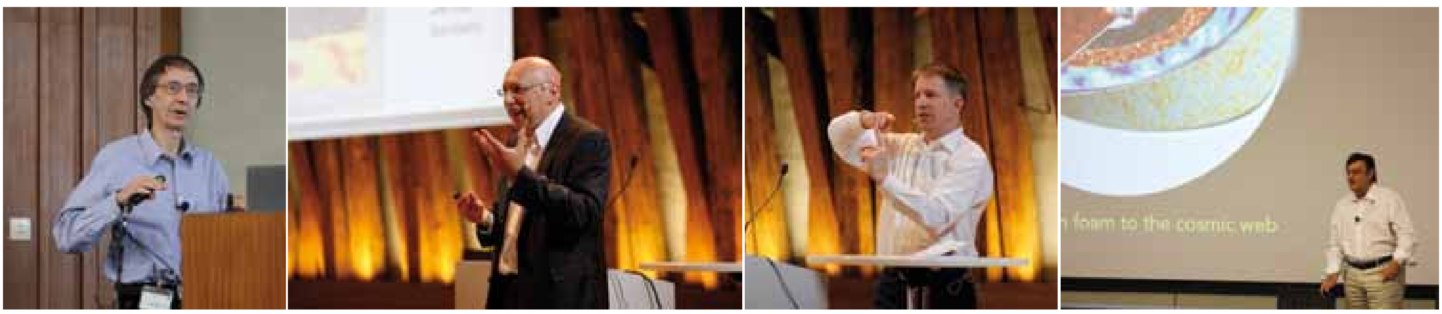
Gregor Jotzu (SPS Award in General Physics, sponsored by ABB) from the quantum optics laboratory of Tilman Esslinger at ETH Zürich talked about realizing fundamental quantum models, for example a topological Haldane model, with ultracold fermions. In the future and already now experiments on ultracold gases of atoms contribute to our understanding of many-body condensed matter physics. It will be interesting to see how quantum optics labs and groups using more conventional experimental approaches will collaborate to address some of the big outstanding questions in condensed matter physics and how new models from atomic physics may be studied in materials. Theory groups that are active in both fields have already helped translating between the two worlds in recent years.

Joël Mesot (director of the Paul Scherrer Institute) presented the current status of the Swiss free electron laser SwissFEL, which is currently under construction at the PSI in Villigen (see also *SPG Mitteilungen* Nr. 39, *Progress in Physics* (32)). Its first ultra-short and ultra-intense pulses of coherent photons are expected in 2017 and will provide unprecedented capabilities for experiments on ultrafast processes in physics, chemistry and biology. Especially the addition of the ATHOS beamline with three experimental stations in the soft X-ray range planned for 2017-2020 will enable completely new experiments in magnetism and on strongly correlated electron systems. The new SwissFEL will certainly contribute many highlights to future SPS Annual Meetings.

Christian Rüegg

Plasma Physics

Prof. Ambrogio Fasoli from the CRPP-EPFL gave a plenary talk entitled "Physics challenges for burning plasmas". This presentation provided a clear insight into the complex mechanisms underlying the control of a burning plasma, in which



... Gerhard Meyer (IBM Rüschlikon), Stefan W. Hell (MPI Göttingen, Nobel Laureate 2014), Arno Rauschenbeutel (TU Wien), François Bouchet (Inst. d'Astrophyisque de Paris), ...

alpha particles, produced by the fusion reactions between Deuterium and Tritium, provide the dominant contribution to the heating of the system. Full understanding of the physics of a burning plasma is obviously key to the success of the current ITER and following DEMO fusion reactor projects.

This year's annual meeting included as well a topical session dedicated to plasma physics. The major part of the talks addressed magnetic fusion-related topics, with speakers from both the CRPP, EPFL and the University of Basel.

A couple of presentations addressed technical issues relevant to ITER, including the cleaning through plasma sputtering of deposits on metallic first mirrors, such as planned for ITER's optical diagnostic systems, as well as the effect of Helium fluxes on Tungsten, used as a plasma facing material, leading to blistering and hole formation.

Radio frequency waves are used to perform localized heating and current drive in magnetic fusion plasmas. An on-going study, carried out on the TORPEX experiment at CRPP, of how these waves are affected by density fluctuations induced by plasma turbulence before reaching their target region was presented. Radio frequency waves are also used for diagnostic purposes. In this context, a feasibility study for a density-profile reflectometer diagnostic for the TCV tokamak at the CRPP was reported on.

Research projects involving numerical simulations were also presented. For example, a talk was given on a novel modeling approach, based on a spectral method, of the self-consistent wave-particle interaction in the cavity of gyrotron oscillators. Gyrotrons are not only used for heating and driving currents in magnetic fusion plasmas, but for other applications as well, such as in Dynamic Nuclear Polarization-enhanced Nuclear Magnetic Resonance systems (DNP-NMR). Another presentation addressed the challenges of porting kinetic simulation codes based on the Particle In Cell (PIC) method to coprocessor (such as GPUs or MICs) -equipped supercomputers. Still another talk presented the progress made in modeling thin film depositions of Niobium on Copper for manufacturing superconducting radio frequency accelerating cavities at CERN.

A final talk was given on the development of a novel electron emissive probe for laboratory plasmas based on a Carbon fibre bundle construction, which should ensure particularly high temperature resistance.

Stephan Brunner

Applied Physics, Geophysics, Atmosphere and Environmental Physics (combined session)

On Tuesday September 1, both orals and posters demonstrated once again this year that physics lies at the basis of many research activities including rock science, seismology, acoustics, optics, electronics, spectrometry, radiative transfers, in parallel to the more fundamental aspects that can also be applied in combination to atmospheric and medical science. Theoretical as well numerical aspects were covered, and a brief overview is given below.

The oral session started with a subject motivated by seismology, where a generalization of the Landau theory of structural phase transitions in matter allowing handling the large geometrical and physical nonlinearities at high pressure, has been presented. Modelling the absorption of microwaves in multicomponent rocks motivated by the energy needed to crush them, thus creating new fracture surfaces, was then presented. After, reactions of nitrogen oxides with hydrated ions where kinetics and thermochemistry by applying a nanocalorimetric approach have been presented with some details. Next, a bi-functional surface emitting and detecting device for sensing applications showed that mid-infrared light sources and detectors offer promising capabilities for chemical sensing of liquids and gases. Another presentation showed that conductance measurements of individual molecular wires revealed detailed insight into the properties and motion of single functional molecules as well as the role of the electronic structure on the charge transport. Two-photon polymerization optionally combined with stimulated emission depletion lithography, allows two and three dimensional polymer fabrication with structure sizes and resolution below the diffraction limit was also shown. Finally, the numerical evaluation of different soundwall shapes and absorptive material was shown to produce useful results.

In the evening, a public lecture by Jens Christensen of the Danish Meteorological Institute, addressed a topic making the headlines: *The future of Earth's climate*. This lecture was very timely prior to the forthcoming United Nations Climate Change Conference, COP21, which will be held in Paris December this year. It was recalled that a central element from Working Group 1 of the IPCC reports has been to point out that the level of atmospheric greenhouse gases has been increasing since the beginning of the industrial revolution due to man's ever increasing need for easily accessible and cheap energy in the form of combustion of fossil fuels. This increase is causing global warming and the warming over the last several decades is very likely mostly, if not entirely

... Ambrogio Fasoli (EPFL-CRPP), Bruno Leibundgut (ESO München). The two public lectures were given by Jens Hesselbjerg Christensen (Danish Meteorological Institute Kopenhagen) and Cornelia Denz (Uni Münster).

The poster exhibition was placed in the central hallway, which was the location, where everybody met everybody and where newest results were vividly discussed.

due to the enhanced combustion taking place worldwide. In its most recent assessment report, AR5, the panel stated that “Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2”.

Stéphane Goyette

TASK-FAKT

Particles, astro-particles and nuclear physics define the scope of the TASK section of SPS, with TASK standing for "Teilchen-, Astro- und Kernphysik". The TASK session was organized jointly with our Austrian colleagues from their "Fachausschuss Kern- und Teilchenphysik" (FAKT). A total of 71 parallel session talks and 14 posters, of which one was selected for the poster award, could be set up covering an overarching spectrum of research activities. In the *High Energy Frontier* session the latest results from three of the four large LHC experiments were discussed on two afternoons, including as well ideas and R&D efforts for detector upgrades that will become important once LHC will ramp up its luminosity to values of up $5 \times 10^{34} cm^{-2} s^{-1}$ and aiming at an integrated luminosity of 3000 fb^{-1} to be collected in the coming two decades. The fourth large LHC experiment, LHCb, was discussed in a session on *B-physics*, together with the Belle experiment; with the high statistics samples available and the unprecedented precision of these detectors, closing in on the CKM matrix elements, and testing for new physics in rare decays offer a rich field for exchange and discussion. A full session dedicated to *Detector R&D* showed the ingenuity needed to perform experiments in special environments involving cryogenic liquid noble gases, tailor made crystals, new or radiation hard electronics and read-out systems at new or upgraded high intensity facilities or space-born satellite missions. *Dark Matter* searches mark an important sector, where cosmology, astrophysics and particle physics meet, aiming to explain the 27% of the total energy density in the universe. A wide program covering axion searches, WIMP detection in large-scale underground experiments, or searching for evidence of dark matter annihilation potentially occurring in the centre of the sun or elsewhere in the universe with the Icecube detector at the South Pole, have all been vividly presented and discussed. The field would not be complete without its rich program of low and medium energy experiments aiming at high statistics using the highest possible intensity beams and reaching utmost precision results on rare processes or processes predicted to be forbidden by standard theory. Indeed, two afternoon sessions were devoted to *Interactions and Fundamental Symmetries at low energies*, enabling rich discussions on such remote fields as high precision studies on nuclear excitations using photon beams, on dedicated isotope beams, preparing for anti-hydrogen spectroscopy, looking for gravity resonance states using ultra cold neutrons, or upgrading existing muon beams for utmost intensities for a future precision measurement of the $\mu \rightarrow eee$ lepton-flavour violating decay of the muon at PSI. All these afternoon parallel sessions were organized such to balance Austrian and Swiss speakers, often resulting in fully alternating the national affiliation of the speakers throughout the sessions. Furthermore, every session started with an invited speaker, giving an overview talk, where also more time was allocated for these speakers. Invited speakers were especially those who won one of the prestigious prizes in either the Austrian or the Swiss physical societies; a tradition worth while keeping for future joint events.

The plenary speaker, Prof. Klaus Kirch from ETH and PSI, completed the overall TASK-FAKT program in Vienna with his talk on *Precision particle physics at low energies* (see p.18 for a more detailed article), a field where Klaus Kirch is truly at home. Kirch’s talk showed once again the multi-faceted landscape of particle physics experiments; where those low energy experiments aiming at highest precision complement others aiming at highest sensitivity. The facilities around the High Intensity Proton Accelerator at PSI provide highest intensities at low momenta of the lightest unsta-

The conference dinner in the "Wiener Heurigen 'Schreiberhaus'" was an opportunity for informal exchange between the societies. Starting a 9 o'clock: Christophe Rossel (EPS President), Herwig Schopper (new honorary member), Felicitas Pauss, Minh Quang Tran (SPS President), Hans Peter Beck (SPS Comittee), Eberhard Widmann (ÖPG President), Helmut Dannerbauer (ÖGAA Secretary), Andreas Schopper (SPS Vice President)

ble particles: neutrons, pions and muons, offering an ideal environment to measure and probe the Standard Model at its extreme in a truly complementary approach than that is done at the LHC. Indeed, often mass scales of virtual exchange particles become accessible this way that otherwise will stay out of reach - even for not yet existing high energy colliders to come in the near or not so near future.

Hans Peter Beck

Theoretical Physics

The session in Theoretical Physics took place on the afternoons of September 2 and 3 with invited and contributed talks. The session was attended by a good number of participants on the first day and by fewer ones on the second. We report here on a small selection of talks.
Jakob Yngvason (Vienna) began his talk by giving mathematical criteria for the phenomena of Bose Einstein condensation (BEC) and of superfluidity. In many instances both are present, but none implies the other. This was illustrated by a model of interacting particles in a random potential in dimension one. It has been rigorously established that, depending on the strength of the interaction and of the disorder, either both phenomena occur, or just BEC without superfluidity.
Samuel Bieri (Paris, formerly Zürich) discussed the ground states of spin models on the Kagomé lattice and its quantum phase diagram. He proposed a dual formulation in terms of fermionic spinons and various ansatzes that are motivated and analysed group theoretically. Jelena Klinovaja (Basel) discussed Majorana states in one-dimensional chains and new proposals of artificial materials for realising them.

Gian Michelle Graf

Careers for Physicists

For the third time the "Careers for Physicists" session took place at the joint meeting. Six talks of physicists in industry showed different career perspectives for young scientists thinking about leaving academic research. This is a topic of interest for many students especially at the end of their studies and the session was well attended.

Elisabeth Schwab went from nuclear physics via the financial industry to the construction industry. She discussed what is important besides good physics knowledge in order to be successful in industry and what additional qualifications one should already look for during one's studies.
Doris Steinmüller-Nethl is the founder of a successful company. She discussed how self-employment is a viable option for physicists looking to work in industry. But she also pointed out the ups and downs of running one's own company.
Soren Charareh, working for a start-up founding agency, discussed, what one needs to think about before founding a start-up and asking for funding. He also presented cases of successful companies that were supported by his agency.
Ilinka Kajgana works in risk management in a bank. She presented this interesting area of work for physicists and her career from a research to a line management position. She also pointed towards topics especially in statistics one should know if one is interested in this field.
Christian Teissl was for many years a technology scout before becoming the director of an innovation centre including a "Fablab". He showed how knowledge acquired at some time during one's life often is of interest again in a different context and it is this knowledge that makes a difference compared to other people.
Finally, Josef Siess summarized the different questions raised during the presentations and discussions in a small workshop, pointing out important issues and giving tips for students looking for a career in industry.

Kai Hencken

Biophysics and Medical Physics

This session was beautifully introduced by a plenary lecture and two invited talks.
The Plenary lecture by Prof. Gijs Wuite of the Amsterdam University entertained us with a new development of acoustic force microscopy and new single molecule techniques for imaging enzymes and proteins interacting with DNA. The

first topic is about the exploitation of an acoustic field in order to apply forces to tethered spheres aiming at measuring elastic properties of the tethering molecules (in the present case it was DNA) at the single molecule level. These measurements are performed in parallel on 2000 individual molecules. The second part dealt with visualizing the interaction of proteins and enzymes, fluorescently marked, with DNA. The invited talks of the session covered two very different topics. The first talk was by Dr. Schreiner of MedAustron, the Austrian facility for cancer treatment using protons or ions. The physical principles and then the medical applications were clearly presented by the speaker. The accelerator facility can also be used for research in different domains beside the medical and biological applications. Prof. De Los Rios of the EPFL Lausanne presented a theoretical approach to an important biological problem, namely the import of proteins into organelles of the cells. His approach combines the statistical physics method with the biological information available for the import, yielding an elegant model explaining the observed facts.
The session was well filled with enough interesting short talks covering a broad range of scientific topics and techniques. The diversity of these short talks shows how lively the biophysics community is and how broad the problems arising when studying the biological matter are.

Giovanni Dietler

Atomic Physics and Quantum Optics

The Atomic Physics and Quantum Optics (APQO) section held five sessions with a total of 32 oral presentations and 32 contributed posters. The first session covered talks on molecular physics, atto- and femtosecond laser spectroscopy, reporting significant progress on truly short timescales. Quantum information was the unifying theme of the second session, where the speakers reported work with photons, neutrons, and superconducting qubits. The third session included a number of talks on quantum optics and quantum sensing with nitrogen vacancy centers in diamond, as well as talks on antihydrogen spectroscopy, atomic magnetometry and novel light sources. In the fourth session, new results on ultracold atoms and matter wave interferometry were presented. Finally, the session on mesoscopic and hybrid systems included several talks on experiments where atomic and atom-like systems are coupled to solid-state quantum systems. The APQO sessions underlined once more how fast the field of atomic physics and quantum optics is currently developing. Several new research groups working in this field have been established at Swiss Universities and Federal Institutes of Technology recently, ensuring that this field and its contributions to the SPS meetings will grow further in the coming years.

Philipp Treutlein

Prof. Karl Unterrainer, Dean of the Faculty "Elektrotechnik und Informationstechnik" of the TU Wien, welcomed the audience in the "Kuppelsaal", a special location for the talk of Nobel Laureate Stefan W. Hell.

History of Physics

The History of Physics session of the 2015 joint Austrian-Swiss meeting took place on Thursday afternoon. The program was for the most arranged by our Austrian colleagues: indeed, we had this year unfortunately no Swiss contributions. The session began with a presentation of Maria Rentetzi who showcased her project devoted to the early history of the International Atomic Energy Agency and its efforts to establish dosimetric standards of radiation. She was followed by Walter Kutschera who explained the method used in 1953 by the German physicist Fritz Houtermans (who ended his career at Berne University) to determine the age of the Earth. Armin Denoth explained next the audience the history of the Innsbruck University tracing in particular its fate through the first two decades of the 19th century when Innsbruck was under Bavarian rule. Reinhard Folk explained then the contribution of Philip Uffenbach, perhaps better known as a rather gifted turn of the 16th century painter, to the science of sundials. Johann Marton from the Stefan Meyer Institute explained the capital role of Stefan Meyer as the first director of his institution. The last two talks addressed some aspects of the rich history of physics at Vienna University, which celebrated this year the 650th anniversary of its foundation. Franz Sachslehner's talk dealt with the history of experimental physics in Vienna following the fate of the physics instruments collection started with the Vienna Jesuit *Museum mathematicum* while the last speaker Wolfgang L. Reiter explained how Vienna physics evolved following governmental initiatives starting with the foundation of a new physics institute in 1850.
The session was largely attended with about 40 listeners, among them some young people who remained through all of the session and seemed to enjoy the historical perspective offered by the speakers.

Jan Lacki

Photo credits:
p. 7, 8 (except top: 4th of 5), 9 (except bottom: 4th of 4), 11 (inset), 12: A. M. Andrews and H. Detz, TU Wien
p. 8 (top: 4th of 5), 9 (bottom: 4th of 4): K. Riedling, TU Wien
p. 13 (right): G. Konrad, Stefan Meyer Inst. for Subatomic Physics, ÖAW
p. 10, 11 (left and right), 13 (left), 14, 15: SPS

epl Journal Poster Award Wien 2015

Antoine Pochelon [1], Gertrud Konrad [2,3]
[1] Swiss Plasma Center, EPFL, Lausanne, [2] Stefan-Meyer-Institute, ÖAW, Wien, [3] Atominstitut, TU Wien

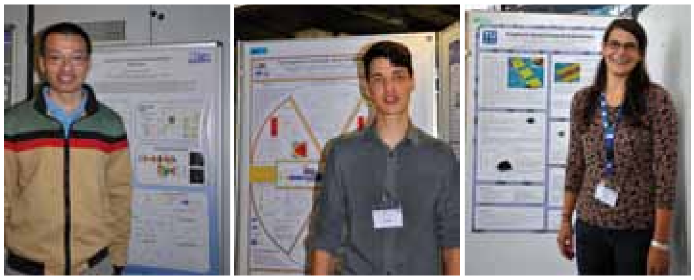
Fostering the scientific activity of young women and men is an important task and at the same time a wonderful responsibility of national physics societies like the SPS and the ÖPG. In this sense, a poster prize is an excellent opportunity to focus predominantly on this class of age and recognizing their effort. It is also a way to focus attention on the manner of communicating, essential in the whole professional life, something that is not always given per se and which generally has to be learnt. In fact, such a prize is not only a way of recognizing excellent work in physics, but here even may be more of promoting quality in the transmission of one's own work. This has finally to do with the art of communication, something essential in the formation of each scientist.

In a short presentation it is not always easy to concentrate in very few words or figures on the main information that people must retain. Just after having been selected, the authors of the three best posters are asked to stand up in the next morning and to present the essential of their work in not more than 2 slides and 2 minutes. In fact a challenging task for which they have not so much time to prepare. But since 2012, the first time that we have instituted this way of doing, we have each time the good surprise to see young people playing the game and presenting the subject of their recognized poster with joy and enthusiasm, a nice event of stimulating atmosphere close to the end of the meeting.

After this four-year experience it is wishful to have a closer look onto the organization of the selection process. First, each presenting author has to mention at the submission if he wishes to participate in the contest. This year we had 56 posters out of 96 participating. During the poster sessions, the presenter has to be really present in front of his poster; we don't want unattended posters. In this year's joint session, three members of the jury came from Austria (Ulrike Diebold, Gertrud Konrad, Jörg Schmiedmayer) and three others from Switzerland (Giovanni Dietler, Jan Lacki, Antoine Pochelon). The selection process is organized in two rounds. In the first round we basically retain only posters that have an introduction or motivations and a conclusion, which is essential for a quick grasp and good readability of a poster. This brings us to a reduced list, where in a second run each member of the jury selects his five best. The winners are the ones collecting the maximum number of points. This whole selection process represents for the jury a substantial and dedicated effort during the conference, since each member has to see all the posters, also those in which he is not specialist: a poster should also be readable by a non-specialist.

From left ro right: Gertrud Konrad (member of the jury), Daniel Moser, Simone Schuler, Qi Liang, Antoine Pochelon (jury chair).

The three winners this year are Simone Schuler, Institute of Photonics, TU Wien (*Graphen-based Integrated photonics*), Daniel Moser, Atominstitut, TU Wien (*Investigation of systematic effects of PERKEO III*), and Qi Liang, Atominstitut, TU Wien (*Calorimetry of Bose-Einstein condensed photon gas*), winning each a prize doted with 200 Euros.



The winners in front of their posters.

We are happy about this collaboration with the epl Journal. It is the place to remember that EPL publishes original, high-quality Letters in all areas of physics, ranging from condensed matter topics and interdisciplinary research to astrophysics, geophysics, plasma and fusion sciences, including those with application potential.

Are you looking for a good recipe? You may want to ponder on the following ingredients:

- try to transport your enthusiasm for the topic with the poster, especially highlight your own motivation
- try to arrange your poster like a story, with an opening (motivation) and end (results, summary, or conclusion)
- be as clear (headings, simple schematics), ordered (boxes or the like), and short (only important information) as possible
- prefer short lists over long text
- find the right admixture of "text" and graphs/pictures
- make sure that graphs/pictures can be understood without (too much) further explanation
- don't use too much/many different colour(s)
- try different/fancy styles, but only if they do not disturb the "logic"
- don't use too many acronyms (and explain them the first time used)
- be prepared to explain your poster in a few minutes, without too many side remarks. Your audience will ask if further detailed questions appear
- be prepared for "general" questions.

Short report on SPS General Assembly in Wien, 2. September 2015

The actions during the last exercise are summarized in the *SPG Mitteilungen* Nr. 46, p. 5 ff. Although the number of new members increased slightly over 2014, it is important to encourage colleagues/friends to become member, since the activities that can be offered grow non-linearly with the number of members. The EPS has published a "Statement on European Energy Policy and Global Reduction of CO_2 emission" (see p. 36 in this issue) The statement has been sent to Mrs. Doris Leuthard. The SPS board will further foster the subject. The contact with IUPAP has been revived and 5 Swiss candidates have been accepted to different IUPAP committees. A new SPS prize on Computational Physics will start in 2016, see p.16. We continue to support activities of our young physicists. We pursue contact with other national Societies, e.g. the SPS participates in the organization of the "SFP Dautreppe Seminar" in Grenoble. The SPS and Swissphotonics are sponsors of the International Year of Light 2015, for which the closing ceremony will be held at EPFL on 5th December 2015.

A fruitful brainstorming took place during the assembly about membership and the engagement of the young people. The number of students and PhD students is low and the help of the professors should be asked to increase the number. A suggestion is to register all the PhD students for free. The Young Physicists Forum had been created with the purpose of attracting students, but it must be completed by other actions. The advantages of becoming a member should be more clearly explained, as well as the networking it can create. The Swiss selection of the International Physics Tournament (Master-Bachelor level) and the Physics Olympiad (SwissPhO, gymnasial level) should be approached too. The "EPS Young Minds" are hoping for new sections in Switzerland, one already exists at ETHZ.

A remark came from the audience that the SPS awards are only meant for young physicists, but there is no "mid-term-carrier prize" yet, which would be a good idea to establish, provided the society's finances allow for it. For 2014, the accountancy shows a benefit.

There are several projects on the agenda 2015-16. Actions to improve the attractiveness of our website have started (contract with a software company). We are strengthening the links with the teachers (VSMP). We are also strengthening the links with sister national societies, like SFP, ÖPG, and possibly with the Netherlands' Physical Society to grasp the reason of their success in terms of membership. The next Annual Meeting will be held at the Università della Svizzera Italiana in Lugano from 23 - 25 August 2016.

Three members of the board have reached the limit of their terms and have to be replaced: Dr. Kai Henken (Physics in Industry) is replaced by Dr. Thomas Brunschwiler and Dr. Patrick Ruch as co-chair, and Prof. Antoine Weis (Atomic Physics & Quantum Optics) by Prof. Philipp Treutlein. With Dr. Tibor Gyalog (Education and Promotion of Physics) leaving, Dr. Hans Peter Beck will chair the section alone in his second term.

The title of honorary member of the SPS was awarded to Prof. Herwig Schopper, see the text below for details.

The President remembers that the Committee is at your service and can be contacted for any questions or suggestions. Your suggestions for topics or articles for the *SPG Mitteilungen* are also welcome.

Antoine Pochelon, SPS Secretary

Ehrenmitgliedschaft für Herwig Schopper

Einer der herausragenden Momente der diesjährigen Jahrestagung in Wien war die Verleihung der SPG-Ehrenmitgliedschaft an Professor Herwig Schopper. Dem Geehrten war die Freude über die Auszeichnung sichtbar anzumerken; ein Zeichen, dass er sie in seinem wahrlich beeindruckenden Palmarès als besonders bedeutsam einstuft. Dem nahezu vollständig anwesenden SPG-Vorstand war ebenfalls die Freude anzusehen, dass ein aussergewöhnlich illustrer und liebenswerter Kollege als Ehrenmitglied gewonnen werden konnte.

Zu Beginn der Zeremonie skizzierte SPG-Vorstandsmitglied Hans-Peter Beck die beeindruckenden Leistungen von Herrn Schopper in experimenteller Physik, als Generaldirektor von Grossanlagen wie DESY und CERN, aber auch sein spezielles Engagement für das multinationale Unesco Projekt SESAME in Jordanien.

Danach erinnerte mit sehr persönlich gehaltenen, warmen Worten Professorin Felicitas Pauss an ihre langjährige Zusammenarbeit mit ihm und überreichte mit SPG-Präsident Minh Quang Tran die Urkunde, zusammen mit einem humorvoll präsentierten Spezialmitgliederausweis.

Herwig Schopper bedankte sich mit herzlichen Worten und verwies gleichzeitig auf die für ihn besonders wichtige Bedeutung der Stätte der Ehrung hin, denn in Wien wirkte Lise Meitner, bei der er anfangs der 1950er Jahre als Post-Doc in Stockholm gearbeitet hatte. Durch sie kam er zu ihrem nicht minder bekannten Neffen Otto Robert Frisch ans Cavendish-Laboratorium in Cambridge, wo er 1957 seine wichtigen Experimente über die Verletzung der Parität in der Schwachen Wechselwirkung durchführte (siehe hierzu seinen Beitrag zu unserer Serie "Milestones in Physics" in den SPG Mitteilungen Nr. 41).

Die SPG beglückwünscht Professor Schopper zur hohen Auszeichnung und wünscht ihm alles Gute für sein weiteres Wirken zum Wohle der Physik.

Bernhard Braunecker

New SPS Committee members

Prof. Philipp Treutlein, (Chair of the Section "Atomic Physics and Quantum Optics")

Philipp Treutlein studied physics at the Universities of Konstanz and Stanford in 1996-2002. At Stanford, he worked in the laboratory of Steven Chu on laser cooling and atom interferometry. Back in Konstanz, he joined Markus Oberthaler's group for his diploma thesis, investigating Bose-Einstein condensates in optical lattices. From 2002-2010, Philipp worked in the laboratory of Theodor W. Hänsch at LMU Munich and the Max-Planck-Institute of Quantum Optics, first as a doctoral student in Jakob Reichel's team and later as leader of his own group. During this time, he performed experiments with ultracold atoms in chip-based microtraps ("atom chips"). He demonstrated a chip-based atomic clock and an atom interferometer, carried out first experiments on quantum metrology with entangled atoms, and explored interfaces of atoms and solid-state systems. In 2010, Philipp was appointed as a tenure-track assistant professor at the University of Basel, where he set up a group working on ultracold atoms, optomechanics, and hybrid quantum systems. In February 2015 he was promoted to associate professor.

With his research group, Philipp explores the quantum physics of atoms and investigates how to exploit them for novel quantum technologies. In their experiments, they use techniques of laser cooling and trapping to prepare atomic gases at temperatures of billionths of a degree above absolute zero. These ultracold atoms are an exceptionally well-controlled quantum many-body system, which allows them to explore fundamental questions of entanglement and decoherence and to push atom interferometry to the ultimate limits of precision. Moreover, Philipp and his team develop quantum interfaces between atoms and solid-state systems such as mechanical oscillators or semiconductor quantum dots. Such interfaces where quantum systems of very different nature interact will play an important role in future quantum technology.

Dr. Thomas Brunschwiler (Chair of the Section "Physics in Industry") and Dr. Patrick Ruch (Co-Chair)

Thomas Brunschwiler is Research Staff Member of the Advanced Micro Integration team at IBM Research - Zurich. He conducts physical research and coordinates governmental and joint projects. In this respect he is pushing the frontiers in 3D integration by scalable heat removal and power delivery, supporting performance and efficiency scaling of high end servers. He performed his Ph.D. in Electrical Engineering at the Technical University of Berlin, entitled "Interlayer Thermal Management of High-Performance Microprocessor Chip Stacks". Currently, he is coordinating two European funded research projects named HyperConnect.eu and CarrICool.eu with the goal to explore percolating thermal underfills, all-copper interconnects and a silicon-interposer platform with heat-removal, voltage regulation and optical communication capabilities. In addition, Thomas Brunschwiler supported the lab director of IBM Research – Zurich as a technical assistant on strategic matters. He authored and co-authored over 70 publications, two book chapter and holds over 30 patents. Thus, he was appointed as an IBM master inventor and received four best paper awards at ITHERM, SEMI-THERM, iMAPS and was honored with the "Harvey Rosten Award for Excellence in the Physical Design of Electronics". He is currently in the committee of several technical conferences, such as ITHERM and InterPACK and is a Senior Member of IEEE.
https://ibm.biz/thomas_brunschwiler

Patrick Ruch is Research Staff Member of the Advanced Micro Integration team at the IBM Research – Zurich laboratory. Prior to joining IBM Research, he studied materials science and received his PhD degree from the ETH Zurich in 2009 for his work performed at the Paul Scherrer Institut on charge storage and aging phenomena in electrochemical capacitors. During his PhD work, Ruch studied dilatational effects in dense ordered and nanoporous disordered carbonaceous materials in situ during electrochemical ion insertion and intercalation by means of X-ray diffraction at the Swiss Light Source, Raman spectroscopy, conductance measurements and Atomic Force Microscopy. He has received the Willi Studer award from ETH Zurich, the EMPA Research Prize, the Alu-Award from the Swiss Aluminium Society and the Young Author Award of the Oronzio and Niccolò De Nora Foundation awarded by the International Society of Electrochemistry. Currently, his main research interests are in energy conversion and storage with applications to sustainable energy technology and efficient datacenters. In this context, he is responsible for exploratory and applied research regarding microfluidic electrochemical energy conversion and solid sorption heat pumps.
https://ibm.biz/patrick_ruch

Neuer SPG-Preis für Arbeiten auf dem Gebiet der computergestützten Physik
Nouveau prix de la SSP pour des travaux dans le domaine de la physique numérique

Die COMSOL Multiphysics GmbH (http://www.comsol.com) stiftet ab dem Jahr 2016 einen SPG-Preis, der jährlich für ausserordentliche wissenschaftliche Arbeiten auf dem Gebiet der computergestützten Physik verliehen wird.

Die COMSOL Gruppe vertreibt Softwarelösungen für multiphysikalische Simulation. Sie ist ein rasant wachsendes High-Tech-Software Unternehmen mit einer nachgewiesenen Erfolgsbilanz und Vision als Marktführer der Branche. COMSOL wurde 1986 in Stockholm gegründet und besitzt inzwischen Niederlassungen rund um den Globus.

Simulation ist heute neben Theorie und Experiment die dritte Säule der Erkenntnis, sie erlaubt Fragen an die Natur zu stellen und Innovationen zu optimieren. Unser Ziel ist es, Ingenieuren und Wissenschaftlern eine mächtige und einfach zu bedienende Software an die Hand zu geben, mit der reale Systeme in Technik und Naturwissenschaft in ihrer vollem Komplexität abgebildet werden können. Zu unseren Kunden zählen Forscher und Entwickler aus Unternehmen, Forschungseinrichtungen und Universitäten.

In der dynamischen Unternehmungskultur von COMSOL setzen wir auf einen intensiven Austausch mit den Schweizer Hochschulen und Nachwuchswissenschaftlern. Dieser Austausch ist für unsere Vorreiterposition gleichermassen Ursache wie auch Verpflichtung.

Wir freuen uns, mit der Vergabe des SPG-Preises talentierte Nachwuchsphysiker anzuregen, sich mit der faszinierenden Welt der computergestützten Physik zu beschäftigen, sich auszuzeichnen und weiterzuentwickeln.

COMSOL Multiphysics GmbH (http://www.comsol.com) offre à partir de 2016 un Prix de la SSP, décerné chaque année pour des travaux scientifiques exceptionnels dans le domaine de la physique numérique.

Le groupe COMSOL fournit des solutions de logiciels pour la simulation multi physique. C'est une société de logiciels high-tech en croissance rapide avec - comme leader du marché - un bilan de succès et une vision éprouvés. COMSOL a été créée en 1986 à Stockholm et possède actuellement des bureaux dans le monde entier.

La simulation est désormais, aux côtés de la théorie et de l'expérience, le troisième pilier des avancées scientifiques; elle permet de poser des questions sur le comportement de la nature et d'optimiser l'innovation. Notre objectif est de mettre à disposition des ingénieurs et des scientifiques un logiciel puissant et facile à utiliser, avec lequel peuvent être représentés dans toute leur complexité des systèmes réels dans les domaines scientifiques et technologiques. Nous comptons parmi nos clients des chercheurs et des développeurs dans les entreprises, les institutions de recherche et les universités.

Dans la culture d'entreprise dynamique de COMSOL, nous nous appuyons sur un échange intensif avec les hautes écoles et universités suisses ainsi que les jeunes chercheurs. Cet échange est ainsi à la fois à l'origine de notre position de pionnier et un devoir.

Nous sommes heureux par l'attribution du Prix de la SSP d'encourager la relève de jeunes physiciens talentueux, de les susciter à se consacrer au monde fascinant de la physique numérique, à se distinguer et à se développer.

New Series "Plenary Talks"

One of the highlights at our annual SPS meetings are always the plenary talks (PT). The topics were carefully selected by a committee to assure a broad coverage of the actual research fields. The invited speakers were asked to present their results in such a way to be understandable by a not-necessarily in this field working physicist. So we aimed on "hot" and didactically best explained physics, and we hope that our members who joined or unfortunately missed the sessions will enjoy the idea and take profit. Most of our plenary speakers agreed to deliver extended versions of their abstract together with some illustrative pictures.
We start here in Nr. 47 with a first selection and will continue in Nr. 48. The articles (marked by the label "PT n/2015", n = 1, 2, ...) will be gathered as own series on our web-page like e.g. our "Progress in Physics" collection.

Bernhard Braunecker

Optoelectronics in two-dimensional atomic crystals

Thomas Müller, Institute of Photonics, Vienna University of Technology, Gußhausstraße 27-29, AT-1040 Vienna

Graphene and related two-dimensional (2D) materials are currently attracting tremendous amount of attention in the research community. With its peculiar band structure and extraordinary physical properties, graphene has inspired interesting applications in nanoelectronics and many other fields. In optoelectronics, graphene has been utilized for the realization of photodetectors [1] and optical modulators [2], covering a wide range of the electromagnetic spectrum from the terahertz to the ultraviolet. Graphene also supports localized and propagating plasmons that are electrically controllable via electrostatic doping with an external electric field [3] – a property that is not available in metal-based plasmonics and that could eventually lead to ultra-small optical modulators and switches.

More recently, another family of 2D materials – transition metal dichalcogenides (TMDs), such as e.g. molybdenum disulphide (MoS_2) and tungsten diselenide (WSe_2) – have come into the focus of interest, as these offer properties that are complementary to those of graphene. Some TMDs are semiconductors with a sizable band gap, which allows the construction of logic transistors [4], light emitters [5], photovoltaic solar cells [6] and other devices. Moreover, physical properties of monolayer TMDs differ significantly from their bulk characteristics. For example, a thickness-dependent indirect-to-direct band gap transition is commonly observed in these materials [7]. In addition, the large exciton binding energies, valley circular dichroism and coherence in monolayers [8] offer exciting opportunities for novel information processing devices.

The value of graphene as an optoelectronic material is due to its wide range optical absorption, the electrical tunability of its optical properties, and the large carrier mobility. These properties allow for the realization of high-speed and broadband electro-optical modulators and photodetectors, employed in optical communication systems. Moreover, the modern trend toward the integration of different optical components side-by-side with electrical circuitry on a silicon chip, has intensified the search for CMOS-compatible photonic materials and technologies, and graphene is considered a promising candidate. Despite the absence of a band gap, graphene shows a surprisingly strong photoresponse near metal/graphene interfaces with an internal quantum efficiency of up to 30 % [1]. In RF photocurrent measurements, no photoresponse degradation was observed up to 40 GHz [9]. A metal-graphene-metal photodetector, consisting of a large number of inter-digitated finger electrodes, was used for the faithful detection of an optical bit stream at a data rate of 10 Gb/s [10]. Integration of a metal-graphene-metal photodetector into an optical microcavity allowed to increase the inherently low (2.3 %) optical absorption in graphene to > 60 % [11].

Fig. 1 shows the integration of a graphene photodetector into a silicon chip [12]. The optical mode in the silicon waveguide is absorbed as the light propagates along the graphene sheet. The potential gradient, originating from different dopings in the metal-covered and uncovered parts of graphene, drives a photocurrent (PC) towards the ground leads. Due to the lack of an electronic band gap in graphene, the photo-generated carriers pass through the potential barriers at the ground-electrodes almost unimpeded, leading to high-speed photodetection even without bias voltage, and hence without dark-current. The photo-responsivity, defined as the ratio of the photocurrent to the input optical power, was determined to be 0.05 A/W. In an improved design [13], the responsivity has recently been pushed to 0.36 A/W, close to that of Ge photodetectors currently employed in silicon photonics. It was further found that the responsivity is approximately flat across all telecommunication bands, unlike the drastic decrease of the response of Ge photodetectors beyond 1550 nm, or strained Ge detectors beyond 1605 nm. The work on photodetectors was complemented by the development of integrated electro-optical modulators [2], paving the way for graphene-based optical interconnects.

Although graphene is suitable for light detection and modulation, the lack of a band gap hampers its use in some other areas of optoelectronics, in particular light emission and photovoltaics. In contrast, due to their direct band gaps in the visible and near infrared, TMD monolayers are perfectly suited for such applications. Most traditional optoelectronic devices are based on p-n junctions. In flatland, such junctions may be realized by lateral or vertical arrangement of atomically thin p- and n-type materials (Fig. 2).

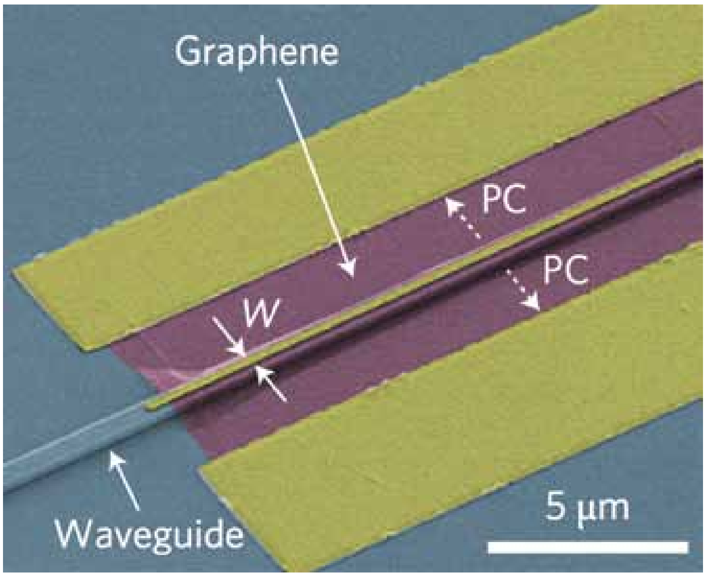


FIG. 1. Silicon chip-integrated graphene photodetector. © Nature Photonics; taken from Ref. [12].

As stable chemical doping is currently difficult to achieve in 2D semiconductors, we used electrostatic doping to form a TMD monolayer p-n junction [5]. In our devices, split-gate electrodes couple to two regions of a mechanically exfoliated WSe_2 flake. By biasing one gate electrode with a positive voltage and the other one with a negative, electrons and holes, respectively, are drawn into the 2D semiconductor and a lateral p-n junction is realized. By driving a forward current through the monolayer diode, electroluminescence emission was obtained. The emission occurs at the same wavelength as the photoluminescence, indicating that the electroluminescence arises from excitonic transitions. The large exciton binding energy in TMDs may thus offer an opportunity for tailoring the emission wavelength by engineering of the dielectric environment. Band gap emission from free carriers was not observed. Electroluminescence efficiencies of up to 0.1 % were obtained, limited mainly by non-radiative recombination in WSe_2 and resistive losses at the contacts.

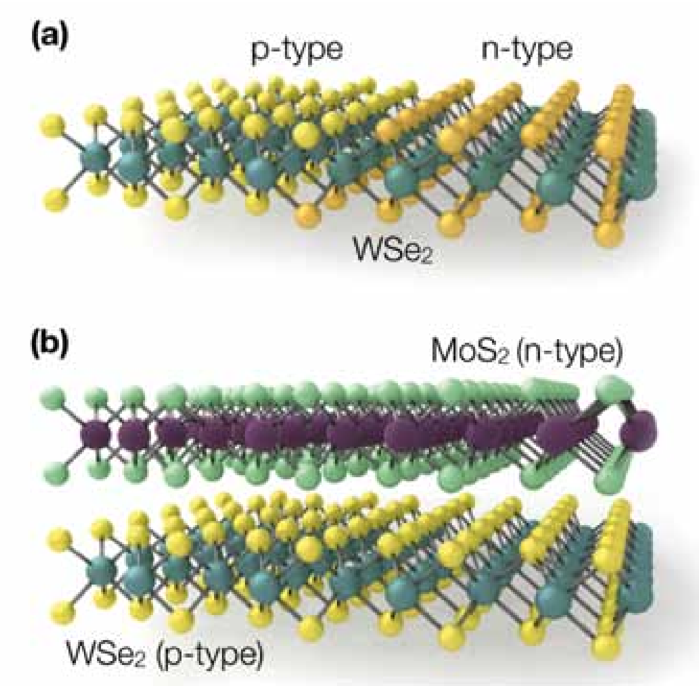


FIG. 2. P-n junctions are formed by joining p-type and n-type semiconductor materials and are at the heart of most optoelectronic devices. Such junctions may be realized by (a) lateral or (b) vertical arrangement of atomically thin p-type and n-type materials.

The lateral arrangement of the junction in above devices does not allow for easy scalability for which a vertical geometry would be desirable. We have thus developed a vertical junction device, in which MoS_2 and WSe_2 monolayers are stacked on top of each other [6]. Owing to the larger electronegativities of Mo and S as compared to W and Se, the electron affinity of MoS_2 is larger than that of WSe_2. As a result, a type-II heterojunction is formed, where the lowest-energy electron states are spatially located in the MoS_2 layer and the highest-energy hole states lie in the WSe_2. Photoluminescence studies confirmed efficient and ultrafast charge transfer between TMDs. The device current as a function of bias voltage displays diode-like rectification behavior.

Under illumination, the heterojunction exhibits a photovoltaic response. Photons are absorbed in WSe_2 and MoS_2, resulting in electron-hole pairs in both layers. Relaxation of the photogenerated carriers then occurs, driven by the type-II band offsets. As the lowest energy electron and hole states are spatially separated, charge transfer occurs across the 2D heterojunction. The relaxed carriers diffuse to the contacts, resulting in a photocurrent. Interlayer recombination occurs during diffusion, which reduces the efficiency of the solar cell. Power conversion efficiency and fill factor were estimated to be 0.2 % and 50 %, respectively. We note that these numbers need to be judged in light of the weak optical absorption of the 2D monolayers. It could be increased by stacking several junctions on top of each other or by plasmonic absorption enhancement.

[1] F. H. L. Koppens, T. Mueller, Ph. Avouris, A. C. Ferrari, M. S. Vitiello, and M. Polini, Nat. Nanotechnol. **9**, 780 (2014).
[2] M. Liu, X. Yin, E. Ulin-Avila, B. Geng, T. Zentgraf, L. Ju, F. Wang, and X. Zhang, Nature **474**, 64 (2011).
[3] A. N. Grigorenko, M. Polini, and K. S. Novoselov, Nat. Photon. **6**, 749 (2012).
[4] B. Radisavljevic, A. Radenovic, J. Brivio, V. Giacometti, and A. Kis, Nat. Nanotechnol. **6**, 147 (2011).
[5] A. Pospischil, M. M. Furchi, and T. Mueller, Nat. Nanotechnol. **9**, 257 (2014).
[6] M. M. Furchi, A. Pospischil, F. Libisch, J. Burgdörfer, and T. Mueller, Nano Lett. **14**, 4785 (2014).
[7] K. F. Mak, C. Lee, J. Hone, J. Shan, and T. F. Heinz, Phys. Rev. Lett. **105**, 136805 (2010).
[8] K. F. Mak, K. He, J. Shan, and T. F. Heinz, Nat. Nanotechnol. **7**, 494 (2012).
[9] F. Xia, T. Mueller, Y. Lin, A. Valdes-Garcia, and Ph. Avouris, Nat. Nanotechnol. **4**, 839 (2009).
[10] T. Mueller, F. Xia, and Ph. Avouris, Nat. Photon. **4**, 297 (2010).
[11] M. Furchi, A. Urich, A. Pospischil, G. Lilley, K. Unterrainer, H. Detz, P. Klang, A. M. Andrews, W. Schrenk, G. Strasser, and T. Mueller, Nano Lett. **12**, 2773 (2012).
[12] A. Pospischil, M. Humer, M. M. Furchi, D. Bachmann, R. Guider, T. Fromherz, and T. Mueller, Nat. Photon. **7**, 892 (2013).
[13] R.-J. Shiue, Y. Gao, Y. Wang, C. Peng, A. D. Robertson, D. Efetov, S. Assefa, F. H. L. Koppens, J. Hone, and D. Englund, Nano Lett., DOI:10.1021/acs.nanolett.5b02368 (2015).

Precision particle physics at low energies

PT 2/2015

Klaus Kirch, ETH Zürich & Paul Scherrer Institut, Villigen PSI

This short article summarizes parts of a plenary talk presented at the joint meeting of the Swiss and the Austrian Physical Societies in 2015 in Vienna. In order to make reading easier, I have here omitted references. However, the interested reader is referred to an article which provides a comprehensive bibliography [K. Kirch, *The Virtue of Precision Particle Physics*, Proc. 2nd Int. Symp. Science at J-PARC – Unlocking the Mysteries of Life, Matter and the Universe, JPS Conf. Proc. **8**, 001003 (2015); *http://journals.jps.jp/doi/10.7566/JPSCP.8.001003*].

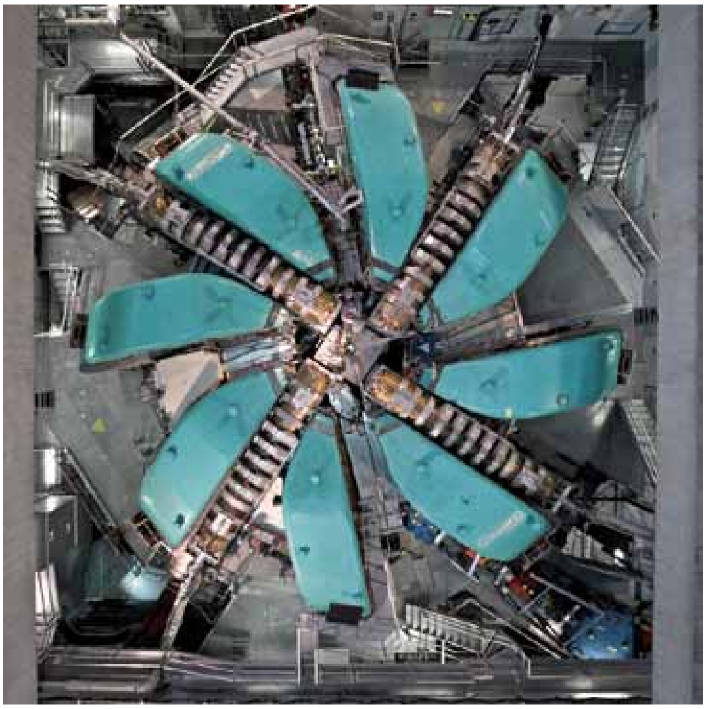
Particle physics experiments at low and at high energies are complementary. Ideally any new particle produced and detected at a high energy collider shows up also, via quantum loop effects, in low energy precision observables. The other way round, a phenomenon observed at low energies may be confirmed by direct production of particles at high energy colliders. However, if the masses of such hypothetical new particles are too large to be produced directly at high, but still limited energies they will manifest themselves only by indirect effects in precision measurements. In fact, the energy at which experiments are performed does not play much of a role anymore if it is low compared to the mass scale of the new physics involved. Often then the practical experimental situation favors low energies at which high intensities of particles can be more easily obtained. This is reflected by the fact that some of the precision measurements and searches at low energies are sensitive to mass scales beyond 100 TeV which is far above what can be reached directly today or even by future colliders.

The direction from observation at low to establishing at high energy has played a key role in the development of our extremely successful theory: The Standard Model (SM) of Particle Physics. The SM unifies electromagnetic, weak and strong interactions in one single theory and – although experimentalists try hard – it didn't fail laboratory tests, yet. It is, arguably besides general relativity, our best theory in physics. This already points to a most obvious deficiency as the SM doesn't know anything about gravity. Moreover, it has many parameters which are not predicted but must be measured, e.g. all particle masses and the coupling strengths of the interactions. And unfortunately, the SM doesn't explain some of our most puzzling astrophysical findings, namely the apparent existence of dark matter and dark energy which seem to tell us that the material we are made of is less than 5% of the energy content of the universe while all the rest is yet unknown. Finally, we have no real clue why the ordinary matter is still here and didn't annihilate with antimatter. They were presumably created in equal amounts following the big bang and while the antimatter seems to be gone, we are still here. All these puzzles provide ample motivation to search for explanations in particle physics beyond the SM.
A promising route is therefore to test predictions of the SM with as sensitive experiments as possible. These are kind of the particle physicists' crash-tests for an unbreakable system so far. Imagine the fascination of ever more precise tests – could a theory be finally 'true'? Too many inconsistencies are apparent. Sooner or later flaws will be found, little deviations from the theory prediction or perhaps even large ones.

Many readers will know about the history of quantum electrodynamics, about the Dirac equation predicting g-factors of 2 for fundamental spin-1/2 particles like the electron and how the electron g-factor is approximately 2, but not just. The experimental deviation from two and its explanation by quantum loop effects, i.e. contributions of virtual particles, lead to a tremendous development. It established quantum electrodynamics as a corner stone of today's SM and lead to ever improving experimental tests of the ever improving theory calculations of the electron g-factor, so far with triumphal agreement. Also the fine structure constant, which is the coupling constant of the electromagnetic interaction, is best determined from these experiments and calculations. The accurate determination of the coupling constants of our known interactions is of key importance and needed for precision predictions of other observables.

Ordinary nuclear or neutron beta decay provides another example of a low energy process. It proceeds via exchange of a virtual heavy W boson mediating the weak interaction. The W has subsequently been detected at high energy accelerators. The standard example of a weak decay process is the decay of a muon, in which a positive muon decays into a positron, an electron neutrino and a muon anti-neutrino thereby conserving the quantum numbers of electric charge and of lepton family. The so-called Fermi coupling constant of the weak interaction is directly extracted from a precision measurement of the muon lifetime. In fact the muon lifetime has recently been measured with an unprecedented precision of 1ppm by the international MuLan collaboration in an experiment at PSI. Today it is by far the best measurement of any lifetime or linewidth of a particle or a state in physics, whether in atomic, nuclear or particle physics.
While the ordinary muon decay provides the Fermi coupling constant as input to the SM, crucial crash tests of the theory are searches for forbidden or very much suppressed alternative decay modes of the muon. These so-called rare decays, like the one of a positive muon into a positron and a photon (as if the muon was an excited positron) or the one of a positive muon into two positrons and an electron, search for lepton flavor violation which is a distinct feature of many theories beyond the SM. The MEG collaboration at PSI is searching for the decay of the muon into positron and photon and has published a 90% C.L. limit of it being less than 5.7×10^{-13} relative to ordinary muon decays. This is the most stringent limit on any rare decay of any particle. The MEG collaboration will soon publish a new result and is pursuing an upgrade of their detector to a next stage. MEG-2 will be an order of magnitude more sensitive again. At the same time the Mu3e collaboration is preparing an experiment at PSI to search for the muon decay into two positrons and an electron improving by three orders of magnitude the sensitivity over the present best limit, aiming first at 10^{-15} and later even beyond.

The experiments mentioned so far use positive muons. Negative muons can be used to replace an electron in an atom, for instance in hydrogen. The wave function of the 200 times



Top view onto the heart of HIPA at PSI, the 590 MeV ring cyclotron which delivers the most powerful 1.4 MW almost continuous proton beam onto targets for the production of secondary particles. One easily recognizes 8 sector magnets and 4 acceleration cavities.

heavier muon has a much larger overlap with the proton than that of the electron and this atom becomes very sensitive to the finite charge distribution of the proton. A recent experiment at PSI has measured the Lamb shift in muonic hydrogen and extracted with unprecedented precision the charge radius of the proton. A discrepancy to determinations with electrons has been found and a global effort is under way to resolve what is today called the proton radius puzzle.

Why do such experiments take place at PSI? The High Intensity Proton Accelerator HIPA at PSI provides with its 1.4 MW beam power of 590 MeV kinetic energy protons on targets the world-wide highest intensities of low momentum pions and muons. It is thus the best and often the only place for such high precision studies. The photograph shows a top view onto the ring cyclotron which was conceived, designed and built more than 40 years ago and has greatly outperformed other machines and superseded its own design current due to continuous upgrades by a factor of more than 20. Today, HIPA drives besides particle physics beam lines also the neutron source SINQ and the muon spin rotation facility SμS. It also serves the new high intensity source UCN for ultracold neutrons and by that provides the highest intensities of the lightest unstable, low energy particles of their kind: mesons (pions), leptons (muons) and baryons (neutrons). The ultracold neutrons are used to search for the permanent electric dipole moment of the neutron (nEDM) which is a quantity extremely small in the SM but it could eventually provide a clue to the matter – antimatter asymmetry problem mentioned above. The international nEDM collaboration at PSI pursues the most sensitive such experiment in a highly competitive field.

It is important to emphasize that these searches are undertaken to find something. While the SM seems unbreakable so far we are convinced that there is more to be found. As it is not exactly clear what and where, it is important to search in many systems where highest sensitivities can be obtained. In the interpretation of the various results particle physics theory is playing a key role. A growing effort is put into model independent analyses which allow combining all kinds of results, from collider searches to lowest energy studies, with the goal to constrain and eventually establish new physics beyond the SM.

Chiral interaction of light and matter in confined geometries

PT 3/2015

Arno Rauschenbeutel
Vienna Center for Quantum Science and Technology, Institute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, AT-1020 Wien, arno.rauschenbeutel@ati.ac.at

Light is usually described as a fully transverse-polarized wave, i.e., with an electric field vector that is orthogonal to the direction of propagation. However, this is only valid in the framework of the paraxial approximation. Yet, in many physically relevant situations, like in strongly focused laser beams, plasmonic structures, or optical microresonators, light is transversally confined in the strongly non-paraxial regime and exhibits transverse intensity gradients that are significant at the wavelength scale. In this situation, Gauss' law generally entails a significant local polarization component that points in the direction of propagation. This component must then oscillate 90° out of phase with respect to the transverse components. The interference of the longitudinal and transverse field components thus results in elliptical polarization for which the plane of polarization is not orthogonal to the direction of propagation, see Fig. 1. In contrast to paraxial light fields, the corresponding intrinsic angular momentum - or the light's spin - can even be perpendicular to the propagation direction. For symmetry reasons, this transverse spin is locked to the direction of propagation of the light field and flips sign when the direction of propagation is reversed. The light thus obtains a locally chiral character.

We have studied such phenomena using silica nanofibers, i.e., cylindrical dielectric waveguides with a diameter smaller than the wavelength of the guided light field. The guided modes of such nanofibers are transversally confined at the wavelength scale and a large fraction of the optical power propagates in the form of an evanescent wave that surrounds the fiber. Emitters at or near the surface of the nanofiber can be efficiently coupled to the nanofiber-guided modes via this evanescent field. Moreover, due to its strong

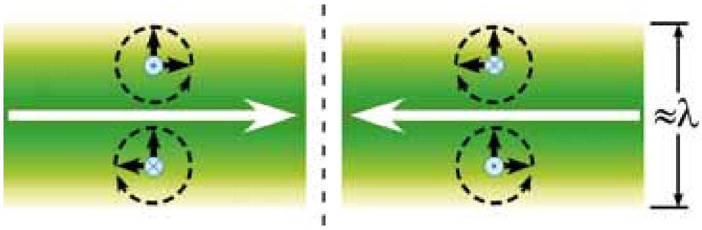


Figure 1: Transverse spin in a propagating light field that is confined at a scale that is comparable to the optical wavelength λ. Polarization components along the direction of propagation oscillate 90° out of phase with respect to the transverse components (black arrows). The resulting elliptical polarization (dashed circular arrow) defines a plane that contains the direction of propagation. The associated spin (blue arrows) changes sign with the direction of propagation; compare left vs. right panel.

intensity gradient, the latter locally exhibits a strongly chiral character.

The chiral interaction of dipolar emitters with such light fields leads to new and surprising effects [1-3]. For example, the intrinsic mirror symmetry of the dipolar emission is broken, i.e., the emitter can be made to send more light into one direction of the waveguide than into the counter-propagating direction. The recipe for realizing such a directional emission is simple: The probability for emitting light into a given nanofiber-guided mode is proportional to $|\vec{d}^* \cdot \vec{e}|^2$, where $\vec{d}$ is the radiating dipole and $\vec{e}$ is the polarization vector of the respective mode at the position of the emitter. Asymmetric emission occurs if this squared overlap is not equal for two counter-propagating modes. We demonstrated this effect both in the classical and in the quantum regime [1, 2].

The classical emitter was a spherical gold nanoparticle [1] with a diameter of 90 nm that was deposited on the surface of a 320-nm diameter nanofiber and that was resonantly excited with laser light sent in from the side at a wavelength of 532 nm, see Fig. 2(a). Here, the nanoparticle acted as a polarization-maintaining scatterer, i.e., the dipole reproduced the polarization of the excitation laser light at its position. By tuning this polarization, the nanoparticle was made to emit its radiation almost exclusively into one waveguide direction. The ratio of the counter-propagating powers was experimentally found to be as large as 40:1. Beyond the fundamental interest, the demonstrated effect might find applications, e.g., for routing light and for optical signal processing in integrated optical environments.

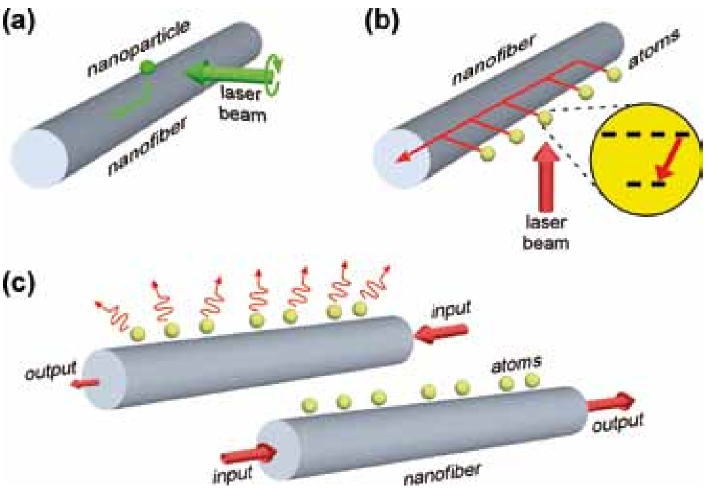


Figure 2: (a) A gold nanoparticle on the surface of a silica nanofiber is side-illuminated with a resonant laser beam and scatters light into the nanofiber-guided mode. A strong asymmetry between the left- and right-propagating photon fluxes is observed in dependence of the laser polarization. (b) In a similar experiment with nanofiber-coupled cesium atoms, the asymmetry depends on the magnetic quantum number of the excited state of the atom. (c) The same experimental system as in (b) allows one to realize a nonreciprocal waveguide if the coupled cesium atoms are prepared in a spin-polarized state.

In a second experiment, we employed cesium atoms as quantum emitters [2]. The atoms were laser cooled to a temperature of a few 10 µK and trapped at a distance of about 200 nm from the surface of a 500-nm diameter nanofiber using suitably chosen far-detuned nanofiber-guided light fields. Like the gold nanoparticle, the atoms were resonantly excited from the side with laser light, see Fig. 2(b). However, unlike spherical gold nanoparticles, cesium atoms are not polarization-maintaining scatterers: They are multilevel atoms and the polarization of their emitted radiation depends, due to dipole selection rules, on the angular momentum quantum numbers of the respective excited state. Thus, the most strongly asymmetric emission is expected if the excited state decays via a so-called cycling transition for which the atoms emit purely circularly polarized light. For other excited states, a weaker or even vanishing asymmetry is expected. This prediction was confirmed in the experiment, thereby showing that a quantum state-controlled directional spontaneous emission can be realized. This might be useful in the context of quantum communication applications but also for the implementation and study of novel correlated states of light and matter which arise from the fiber-mediated asymmetric coupling between atoms. Moreover, by observing the unbalanced scattering, one might detect and identify emitters with an intrinsic polarization asymmetry.

Finally, we demonstrated that the chiral nature of light in optical nanofibers can be exploited for the realization of an optical isolator, i.e., an optical component with a direction-dependent transmission [3]. Such optical isolators are crucial devices, e.g., when it comes to protecting sensitive laser light sources from harmful back-reflections. Ideally, they should let light pass without attenuation in the forward direction while blocking light that propagates in the backward direction.

In order to achieve this functionality, we coupled spin-polarized atoms to a nanofiber, see Fig. 2(c). The spin polarization was achieved by so-called optical pumping, i.e., by exposing the atoms to suitably polarized near-resonant light. The atoms then acted as polarization-dependent scatterers that exhibit different interaction cross-sections for right- and left-circularly polarized light. The resulting chiral interaction between the atoms and the guided light thus led to nonreciprocal, i.e., direction-dependent, transmission: the atoms scattered most of the light that propagated in one direction out of the waveguide while the light that propagated in the other direction coupled only weakly to the atoms and passed through the waveguide with small losses.

It is worthwhile noting that the demonstrated effect can in principle be implemented without applying any external magnetic field. Conventional optical isolators, so-called Faraday isolators, employ magneto-optical materials and require external magnetic fields in order to break the otherwise reciprocal transmission. In contrast, our optical isolator is purely spin-based: It solely makes use of the time-reversal symmetry properties of the atomic spin and neither relies on the interaction of this spin with an external magnetic field nor on the atomic magnetic dipole moment that may be caused by the spin [3].

We believe that this result lays the foundations for a new class of nanophotonic devices based on chiral light-matter interaction which complement the existing components for conventional integrated optical signal processing. Moreover, the demonstrated scheme is compatible with ultra-low light levels down to single photons, a prerequisite for quantum applications. This property, along with high isolation, is not fulfilled by other integrated optical isolators that are currently available. We therefore consider our isolator concept to be attractive, e.g., for quantum information processing with photons on optical chips.

References:

[1] J. Petersen, J. Volz, and A. Rauschenbeutel, "Chiral nanophotonic waveguide interface based on spin-orbit coupling of light," Science **346**, 67 (2014).

[2] R. Mitsch, C. Sayrin, B. Albrecht, P. Schneeweiss and A. Rauschenbeutel, "Quantum state-controlled directional spontaneous emission of photons into a nanophotonic waveguide," Nature Commun. **5**, 5713 (2014).

[3] C. Sayrin, C. Junge, R. Mitsch, B. Albrecht, D. O'Shea, P. Schneeweiss, J. Volz and A. Rauschenbeutel, "Optical diode based on the chirality of guided photons," arXiv:1502.01549.

Studying band-topology with ultracold fermions in an optical lattice: Experimental realisation of the Haldane model

PT 4/2015

Gregor Jotzu, Michael Messer, Rémi Desbuquois, Martin Lebrat, Thomas Uehlinger, Daniel Greif & Tilman Esslinger
Institute for Quantum Electronics, ETH Zürich, CH-8093 Zürich

The concept of topology is usually illustrated by considering a sphere and a torus: Both objects have curved surfaces, however, when integrating their Gaussian curvature over the entire surface, the result is 4π for a sphere, but zero for a torus. Interestingly, these values do not change when smoothly deforming these highly symmetric objects into more complicated ones. For example, when deforming a sphere into a bowl or a spoon, the curvature of the surface does of course change locally, but the integral remains 4π. All of these objects then belong to the same topological class. On the other hand, a torus can also be deformed into a tea cup, but the integrated curvature remains zero. Clearly then, a torus cannot simply be transformed into a sphere, it is necessary to cut open the surface and glue it back together again - they belong to distinct topological classes.

Topology is however not only an abstract mathematical concept; it can also appear in unexpected places in the physical world. In the context of condensed matter physics, topology has shifted into focus with the discovery of the quantized Hall effect, which was shown to arise from a change in the topology of the electron wave function when an external magnetic field is applied [1]. In 1988, F. D. M. Haldane proposed a Hamiltonian for a material which could intrinsically feature non-trivial topological properties [2]. Although physical implementation has been considered unlikely, Haldane's model has provided the conceptual basis for theoretical and experimental research exploring topological insulators and superconductors [3, 4]. The tight-binding model is based on a honeycomb lattice with two additional elements (see Figure 1a). First of all, an offset between neighbouring sites breaks inversion symmetry. Second, time-reversal symmetry is broken by the presence of complex next-nearest-neighbour tunnelling. Depending on which one of these broken symmetries dominates, the model features distinct topological regimes, with a topological transition between them.

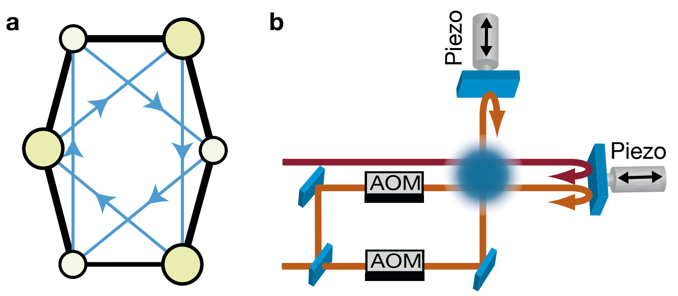


FIG. 1: (a) The Haldane model consists of a tight-binding honeycomb lattice with a variable energy-offset between neighbouring sites. In addition, it features complex next-nearest-neighbour tunnelling (with a phase defined along the blue arrows). (b) The optical lattice is realised by a combination of laser beams with different frequencies (indicated by different colours), which are controlled and phase-stabilised using acousto-optical modulators (AOMs). The retro-reflecting mirrors are oscillated using piezoelectric transducers.

In order to implement Haldane's model [5], ultracold non-interacting fermionic ^{40}K atoms are trapped in an optical lattice created by interfering laser beams. The phase and frequency of three retro-reflected beams is controlled such as to create a honeycomb lattice, see Figure 1b. This lattice geometry is also the basis for the electronic properties of Graphene [6]. It gives rise to a band structure where the two lowest bands touch at two quasimomentum-points surrounded by a linear dispersion relation, known as Dirac points. A first experimental challenge consists in detecting the presence of these Dirac points: This is realised by loading atoms into the lowest band of the lattice, accelerating them towards the Dirac points and observing where atoms are transferred to the higher band [7, 8].

The optical lattice can now be deformed such that an offset between neighbouring sites is introduced. A gap then opens at both Dirac points, corresponding to an insulating material. The gap, which has the same value as the energy-offset between sites, is measured by observing how the transfer to the higher band reduces. Introducing complex next-nearest-neighbour tunnelling is more challenging. For electrons, this would correspond to a staggered configuration of magnetic fluxes, but atoms are electrically neutral. Therefore a different approach was used, based on a theoretical proposal in the context of Graphene [9]: If a rotating force is applied to particles in a honeycomb lattice, the system - on longer time-scales - behaves as though imaginary next-nearest-neighbour tunnelling were present. The induced tunnelling also opens a gap at both Dirac points. This phenomenon is already very fascinating on its own: it implies that it is possible to transform a conductor into an insulator by shining circularly polarized light on it, which promises interesting technological applications. This approach, realising novel Hamiltonians by considering the long-term behaviour of periodically driven systems, is an emerging field of research known as "Floquet engingeering" [10].

In our experiment, the rotating force is realised in an inertial frame, by moving the entire lattice on a circular trajectory. This is done by moving the mirrors which reflect the laser beams forming the lattice, using piezo-electric crystals (see Figure 1b). The resulting gap-opening at the Dirac points is again observed as a reduction of the transfer to the higher band. In contrast, oscillating the lattice on a linear trajectory (which does not break time-reversal symmetry and therefore does not induce imaginary tunnelling), does not open a gap.

When time-reversal symmetry is broken, the lowest band is expected to have a different topology than when inversion symmetry is broken. However, this difference in topology cannot be detected by considering the energy of the band; the eigenstates now play the decisive role. Similar to the Gaussian curvature in the example of the sphere and torus above, the topology of a band is characterized by integrating the Berry curvature of the band. The Berry curvature [11] is a generalized form of a magnetic field in any parameter

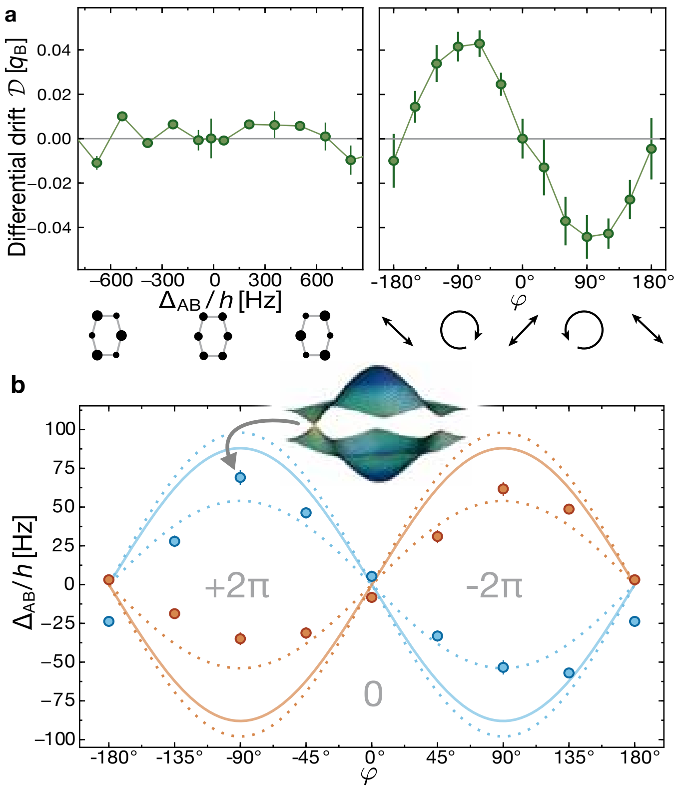


FIG. 2: (a) Differential drift measurements reveal the topology of the lowest band. When inversion symmetry is broken by a site offset Δ_{AB} (as illustrated), no signal is observed. When the lattice is modulated on an elliptical trajectory (with phase φ between the two retro-reflecting mirrors), a drift appears, with a sign which depends on the chirality of the trajectory (as illustrated). (b) The topological transition between trivial regimes, where the integrated Berry curvature is zero (grey numbers), and non-trivial regimes (± 2π), is mapped out as a function of φ. On the transition line, the band structure becomes gapless at one Dirac point, as illustrated.

space (in this case quasimomentum space) and sets the geometric quantum phase picked up on a closed trajectory, a generalisation of the Aharonov-Bohm phase.

When a gap is opened at the Dirac points, Berry curvature appears in their vicinity. For broken inversion symmetry, as caused by a site offset, this Berry curvature is opposite at the two Dirac points and therefore adds up to zero, corresponding to a trivial topology. When time-reversal symmetry is broken by complex next-nearest-neighbour tunnelling, the curvature is the same at both points. It integrates up to the quantized value of either +2π or -2π, depending on whether the lattice is moved on a clockwise or anti-clockwise trajectory. In order to detect this Berry curvature, atoms are accelerated through the lowest band such that they sweep out the entire Brillouin zone. In analogy to a Lorentz force, the Berry curvature then gives rise to a transverse drift [12, 13]. Comparing this drift for opposite accelerations then allows for distinguishing different topological regimes: In the trivial regime, no signal is observed, whilst in the non-trivial regime the signal appears and inverts when the curvature changes sign, see Figure 2a.

Having shown that the two regimes explored above are topologically distinct, we also verify that moving from one to the other implies a process analogous to cutting and gluing. In the context of a band structure, this corresponds to closing and re-opening a gap between bands. When both inversion and time-reversal symmetry are broken, i.e. when a site offset and imaginary next-nearest-neighbour tunnelling is present, the two contributions to the gap now either add up or are subtracted from each other - depending on which Dirac point we consider. Therefore, when both contributions are equal, the gap closes at one Dirac point, signalling the transition between two topologies. Using the transfer to the higher band, we now measure the gap at each Dirac point separately, and identify the gap-closing points to map out the topological transition experimentally. The results, as shown in Figure 2b, are compared to the theoretical expectation including uncertainties in the lattice structure, and show that a transition between topologically distinct regimes can be measured using ultracold fermions.

Whilst theoretically computing this transition line was still straightforward for the non-interacting system presented here, the situation changes when interactions between atoms are introduced. Theoretical predictions - including numerical simulations - then become very challenging, and in fact it is not yet clear whether interactions stabilize or destroy the non-trivial topology which appears in the Haldane model. For ultracold atoms, interactions can be freely tuned [14, 15], so they should be an ideal platform to answer this question experimentally, which would be an exciting application of the concept of "quantum simulation" [16].

[1] D. J. Thouless, M. Kohmoto, M. P. Nightingale, and M. den Nijs, Phys. Rev. Lett. **49**, 405 (1982).
[2] F. D. M. Haldane, Physical Review Letters **61**, 2015 (1988).
[3] M. Z. Hasan and C. L. Kane, Reviews of Modern Physics **82**, 3045 (2010).
[4] B. A. Bernevig and T. L. Hughes, *Topological insulators and topological superconductors.* (Princeton Univ. Press, 2013).
[5] G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, and T. Esslinger, Nature **515**, 237 (2014).
[6] A. H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov, and A. K. Geim, Reviews of Modern Physics **81**, 109 (2009).
[7] S. Kling, T. Salger, C. Grossert, and M. Weitz, Phys. Rev. Lett. **105**, 215301 (2010).
[8] L. Tarruell, D. Greif, T. Uehlinger, G. Jotzu, and T. Esslinger, Nature **483**, 302 (2012).
[9] T. Oka and H. Aoki, Physical Review B **79**, 081406 (2009).
[10] M. Bukov, L. D'Alessio, and A. Polkovnikov, Advances in Physics **64**, 139 (2015).
[11] M. V. Berry, Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences **392**, 45 (1984).
[12] M.-C. Chang and Q. Niu, Physical Review Letters **75**, 1348 (1995).
[13] D. Xiao, M.-C. Chang, and Q. Niu, Reviews of Modern Physics **82**, 1959 (2010).
[14] M. Lewenstein, A. Sanpera, and V. Ahunger, *Ultracold atoms in optical lattices: Simulating quantum many-body systems* (Oxford Univ. Press, 2012).
[15] P. Törmä and K. Sengstock, *Quantum gas experiments: Exploring many-body states* (Imperial College Press, 2015).
[16] I. M. Georgescu, S. Ashhab, and F. Nori, Rev. Mod. Phys. **86**, 153 (2014).

Shedding light on Dark Photons [1]

PT 5/2015

Josef Pradler, Institute of High Energy Physics by the Austrian Academy of Sciences

The Standard Model of particle physics is incomplete. Neutrinos carry mass, and cosmology and astrophysics call for an extension of the Standard Model (SM), through the need for dark matter. In almost a century of progress, particle Dark Matter (DM) remains the single, most powerful physics concept able to explain otherwise anomalous observations on all cosmological scales, from the motions of stars in the solar neighborhood to the gravitational imprint of non-luminous matter onto the horizon of the observable Universe. Yet, the concrete, microscopic properties of the hidden sector remain essentially unknown. The particle identity of dark matter remains a mystery, and it is a puzzle that has occupied physicists for many years.

While the number of theoretical possibilities for DM remains enormous, several model classes can be broadly identified. If new physics exists at or near the electroweak scale, a weakly interacting massive particle (WIMP) becomes a viable option. The WIMP paradigm assumes the existence of a relatively heavy particle, typically with a mass in the GeV/c² to TeV/c² range, having sizable couplings to the Standard Model. The simplest models of this type also predict a significant scattering rate for WIMPs in the galactic halo on nuclei, when up to 100 keV of WIMP kinetic energy can be transferred to atoms, offering a variety of pathways for detection. A whole battery of such direct detection experiments are now seeking to observe the recoil scattering of galactic Dark Matter particles on nuclei.

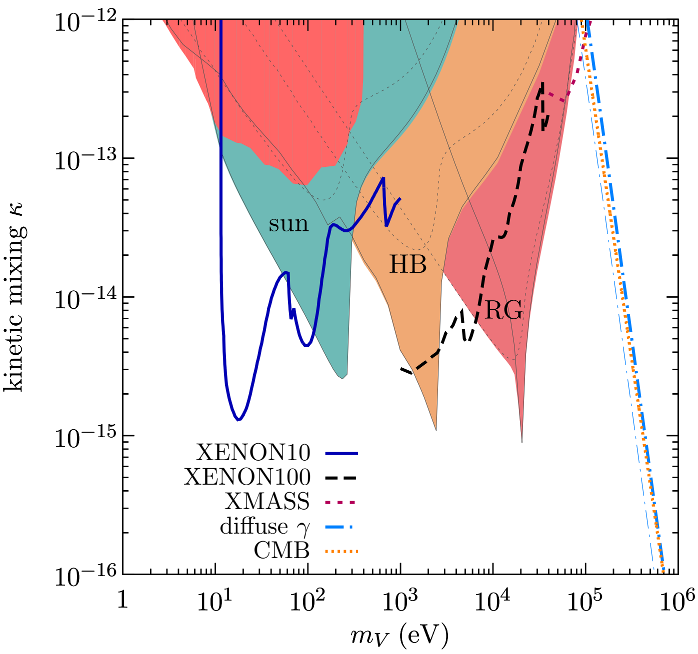


Figure 1: Laboratory, direct detection limits on dark photon dark matter exceed astrophysical constraints; taken from [1].

Another possibility for DM are superweakly interacting particles. Dark matter of this type is harder to detect directly, as the couplings to the SM are usually smaller than those of WIMPs by many orders of magnitude. Metastability of such states offers a pathway for the indirect detection of photons in the decay products, as is the case for metastable neutrino-like particles in the O(10 keV/c²) mass range.

A prominent representative of the latter class are "dark photons", new massive vector particles V. They are introduced as an extension of the SM through their kinetic mixing term to the hypercharge field strength of the SM. Below the electroweak scale, the effective kinetic mixing, $\kappa V_{\mu\nu}F^{\mu\nu}$, of strength κ between the dark photon V and photon A with respective field strengths $V_{\mu\nu}$ and $F^{\mu\nu}$ is the most important one. This simple model has been under significant scrutiny over the last few years, as the minimal realization of one of the few UV-complete extensions of the SM (portals) that allows for the existence of light weakly coupled particles.

In [1] we show that dark matter made from dark photons can be detected with direct detection experiments—albeit superweak couplings to SM. Unlike a nuclear recoil, the signature of WIMPs, dark photons offer a signature by being absorbed by atomic electrons when the dark photon mass is in the 10 eV/c² - 100 keV/c² window [2]. The exquisite sensitivity to ionization signatures at experiments that employ liquid scintillators then allows stringent constraints to be placed on dark photon dark matter. In particular, the experimental results by the Xenon10 and Xenon100 collaborations put in place a limit on the coupling constant of the dark photon to electrons, eκ (e is the electric charge), that ranges as low as $\kappa \sim O(10^{-15})$.

Figure 1 shows the derived laboratory exclusions as labeled. The lower mass limit, 12 eV/c², is determined by the ionization threshold of liquid xenon; the dark photon moves at non-relativistic speed through the galactic halo, and when it is being absorbed, its mass is converted into kinetic energy of the electron. Above a vector mass of ~100 keV/c² the lifetime of V becomes comparable to the age of the Universe. A dark photon of this mass cannot decay into electrons, but it may decay, through a quantum loop, into three photons. This possibility is restricted through astronomical observations of the diffuse gamma ray background and through the measurements of the cosmic microwave background (CMB).

Perhaps most remarkable, the ensuing laboratory limits exceed those from stellar energy loss arguments of the sun, horizontal branch stars (HB) and red giant stars (RG) over a significant mass range. Stars are supreme probes to detect the presence of light, feebly interacting particles, and these astrophysical limits are usually much superior to laboratory tests. The new particles can be produced in the stellar interior and carry energy from the interior to the outside. Dark photons are subject to those constraints, but it is one of the rare cases where direct limits are in fact superior. Indeed, one can use the very same dark matter experiments to search for the solar flux of dark photons [3].

A different range in dark photon mass, 1 MeV/c² - 10 Gev/c², is under tremendous scrutiny in recent years as it defines

[1] with excerpts from the original research papers

a window of opportunity for "intensity frontier" experiments [4]. Dark photons in this mass range cannot be dark matter; they decay to electrons, muons, pions—any states with electromagnetic charge and within kinematic reach. However, unstable dark photons still play a prominent role as "dark force" carriers between other dark matter particles. They regulate the dark matter annihilation cross section, and for this V particles have received by far the most attention in the literature.

The dark photon decay offers an experimental signature that follows the production in intense low-energy electron beams. Some of the experimental efforts are depicted in the upper part of Figure 2. As can be seen, the experimental sensitivity is restricted to kinetic mixing parameters $\kappa > 10^{-8}$. If the kinetic mixing parameter κ becomes smaller, the link to the SM is severed, and all laboratory efforts of detection fail (even when considering futuristic experimental setups.) Here, cosmology comes to the rescue.

In the past two decades, there has been impressive progress in our understanding of the cosmological history of the Universe. A variety of precision measurements and observations point to a specific sequence of major cosmological events: inflation, baryogenesis, big bang nucleosynthesis (BBN), recombination and the decoupling of the cosmic microwave background (CMB). While our knowledge of the earliest moments is necessarily uncertain, BBN and the CMB have a firm position in cosmic chronology. This by itself puts many models of particle physics to a stringent test, as the increasing precision of cosmological data leaves less and less room for deviations from the minimal scenario of standard cosmology.

For kinetic mixing $\kappa < 10^{-11}$ the decay of a dark photon to SM particles becomes of truly macroscopic lifetime, exceeding one second. The energy stored in the relic population of dark photons is then released during BBN and later, at recombination. For BBN, this leads to departures in the nuclear reaction networks that determine the light element abundances of deuterium, helium, and lithium. For the latter, the anomalous energy deposition leads to an altered recombination history that can e.g. be detected in the polarization of the CMB. Detailed calculations then expose a truly remarkable sensitivity of $\kappa \sim 10^{-10}$ - 10^{-14} for BBN and $\kappa \sim 10^{-16}$ - 10^{-17} for CMB. The latter corresponds to an electron-dark photon coupling of effective fine-structure constant $\alpha_{eff} = \alpha\kappa^2 \sim 10^{-37}$ - 10^{-38} ! Such small couplings render these very dark photons completely undetectable in terrestrial particle physics experiments, and cosmology remains our last resort to test such new physics scenarios [5].

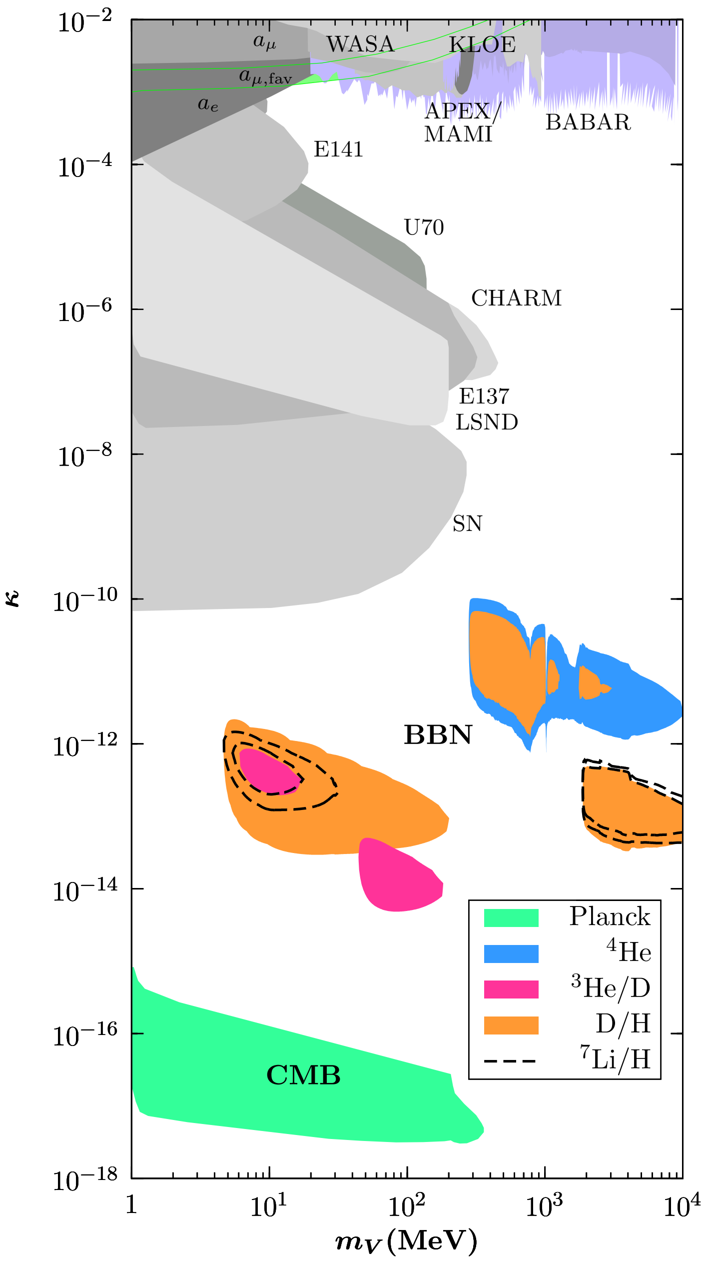


Figure 2: Cosmological constraints from light element abundance predictions (BBN) and from the measurements of the cosmic microwave background (CMB) in the "intensity frontier" mass window 1 MeV/c² - 10 GeV/c²; taken from [5]

[1] Direct Detection Constraints on Dark Photon Dark Matter, H. An, M. Pospelov, J. Pradler, A. Ritz, Phys.Lett. **B747** (2015) 331-338.
[2] Bosonic super-WIMPs as keV-scale dark matter, M. Pospelov, A. Ritz, M. Voloshin, Phys.Rev. **D78** (2008) 115012
[3] Dark Matter Detectors as Dark Photon Helioscopes, H. An, M. Pospelov, J. Pradler, Phys.Rev.Lett. **111** (2013) 041302
[4] Working Group Report: New Light Weakly Coupled Particles R. Essig et al, arXiv:1311.0029
[5] Cosmological Constraints on Very Dark Photons, A. Fradette, M. Pospelov, J. Pradler, A. Ritz, Phys.Rev. **D90** (2014) 3, 035022

Progress in Physics (50)

Formation of rogue waves under forcing fields

Maura Brunetti
GAP-Climate, Institute for Environmental Sciences, University of Geneva

The most impressive way to understand what a rogue wave is compared to ordinary waves, is to look at pictures showing a wall of water approaching ships like that in Fig. 1. Rogue waves are large amplitude waves that can appear suddenly in the open ocean, the wave crest to trough height exceeding twice the significant wave-height (defined as the mean of the upper third of the rest of the waves). Due to their large amplitude, we can easily understand how seriously these rogue waves can damage large ships or offshore structures, as reported several times in the media and in the scientific literature, and why it is important to understand how they form in order to improve the prediction of their occurrence. Rogue waves do not appear only on the ocean surface, but they are observed in many different fields of physics such as high-power pulse filamentation (Bergé *et al.* 2007), noise-induced solitons in fiber supercontinuum generation (Solli *et al.* 2007), propagation effects in optical fibers (Kibler *et al.* 2010) or in plasmas (Veldes *et al.* 2013), spatial patterns in cavities (Montina *et al.* 2009). In a broad sense, rogue waves can be defined as localised high-amplitude, statistically-rare events in a system, appearing in the tails of the associated probability distribution. In this broad sense, such huge waves are observed in many domains other than physics, such as for example financial science.

Figure 1. A wall of water approaches the Stolt Surf in October 1977. The chemical tanker encountered a wave of at least 22 m, much higher than the significant wave height estimated to 10 m. Photo credit: Karsten Petersen, www.global-mariner.com

Rare occurrence in field measurements makes the study of such phenomenon in the natural oceanic environment very difficult. A way to circumvent this problem is to use water-tank experiments, but the idealized setup of the experimental configuration limits the formation and propagation scenarios that can be analysed. Optical systems are in general more flexible and have been shown to be suitable for investigating realistic nonlinear propagation scenarios in a reproducible way (Dudley *et al.* 2014). This is an example of why the interaction between different fields in physics has been deeply developed in the last decades (see for example the ongoing ERC Multiwave project, www.ercmultiwave.eu).

Analogies in the occurrence of rogue waves in different domains have deepened our understanding of the phenomenon.
Despite this interdisciplinary effort, an explanation for the formation of rogue waves is still debated. Different possible mechanisms have been found (Kharif *et al.* 2003, 2009, Onorato *et al.* 2013), from linear processes (as for example caustic focusing in wave propagation discussed in Mathis *et al.* 2015), to nonlinear mechanisms (modulational instability), or complex dynamical processes (collisions of breathers Akhmediev *et al.* 2009 or solitons Armaroli *et al.* 2015). Interestingly, the common effort in understanding the rogue wave formation mechanisms has the consequence that many approaches are tested and shared by different communities in domains at the forefront of the research in nonlinear dynamical systems and non-equilibrium thermodynamics (see for example Hadjihosseini *et al.* 2014, Armaroli *et al.* 2015).

Starting from the Euler equations in the uncompressible-fluid approximation, one can obtain propagating solutions at the ocean surface. In the deep-water limit, i.e. when the ocean depth is larger than the wave-length, these surface waves are dispersive and propagate under the effect of gravity with wave periods T in the range between 0.1 s and 5 minutes and group velocity $c_g = gT/(4\pi)$, where g is the gravitational acceleration. At leading order, i.e. by assuming narrow-banded waves of moderate amplitude that mainly propagate in one direction in a dispersive medium, the propagating waves can be modeled by the nonlinear Schrödinger equation (NLSE), written in its normalized form as follows:

$$i\frac{\partial A}{\partial t} - \frac{1}{2}\frac{\partial^2 A}{\partial x^2} - A|A|^2 = 0$$

where $A(x,t)$ is the wave envelope, and t and x are (normalized) propagation time and distance, respectively, in a frame moving at the group velocity of the input pulse. The focusing (local concentration of energy) is obtained by the mutual effect of dispersion (the second term) and nonlinearity (the last term in the above equation).
Exact solutions of the NLSE, such as the Akhmediev breather (Akhmediev & Komeev 1986) or the Peregrine soliton (Peregrine 1983), play a crucial role in the formation of rogue wave (see Fig. 2): they are supposed to form the deterministic backbone of nonlinear focusing of wave energy in a background wave state.

However, the nonlinear evolution implies a broadening of the spectrum and a steepening of the waves, and suddenly brings the system in a regime that can no longer be described by the NLSE. Higher-order effects need to be included (higher-order dispersions and nonlinearities, described by more general models, e. g. Dysthe 1979 and Ankiewicz *et al.* 2013). Within these generalized models,

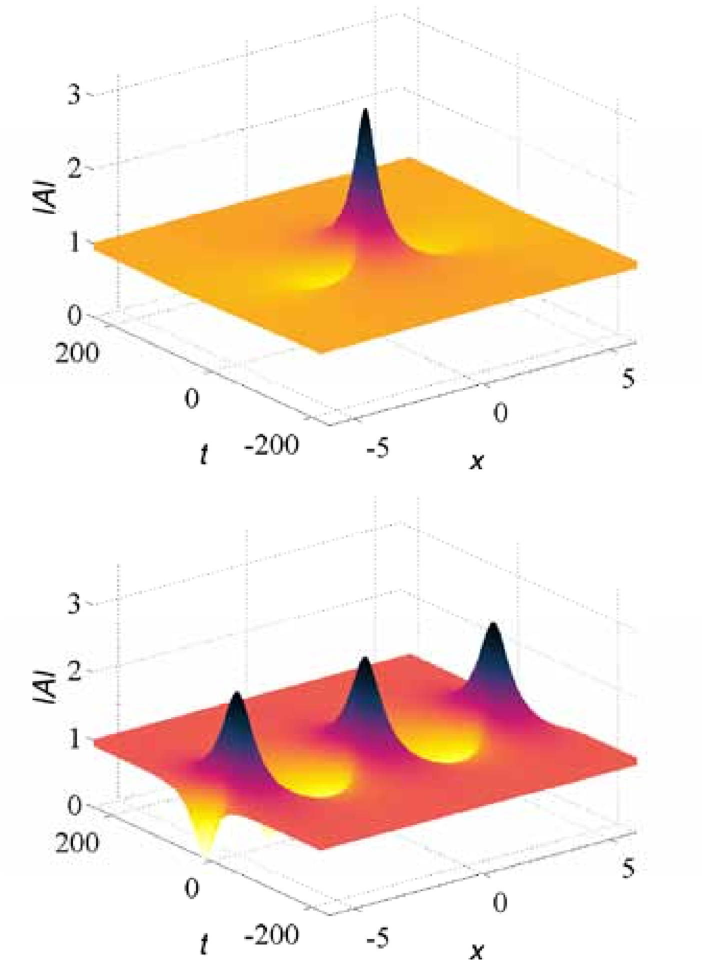


Figure 2. Exact solutions of the NLSE. Top: Peregrine soliton. Bottom: Akhmediev breather.

nonlinear superposition of first-order solutions (such as the Peregrine soliton or the Akhmediev breather) are able to form rogue waves with amplitudes much larger than the constituent breathers, as shown in numerical and laboratory experiments (Akhmediev *et al.* 2009, Erkintalo *et al.* 2011, Armaroli *et al.* 2015).
The evolution and the formation of rogue waves are also affected by dissipative effects (Segur *et al.* 2005) and external forcing of different origin (wind for ocean waves, Raman scattering in optical systems, etc.) that need to be included in the models. The complexity of this picture explains why a unified approach that describes the formation of rogue waves is still missing and why a huge effort in sharing methods and ideas is under way in the scientific community.

Since ocean waves are under the continuous action of wind, it is worth asking how the constituent breathers modify in a forcing regime. It is known that breather solutions, that undergo periodic energy exchange with a finite background, correspond to the evolution of the modulational instability, a central process of physical systems described by the NLSE (Akhmediev & Korneev 1986, Zakharov & Ostrovsky 2009). Thus the question is equivalent to asking how the modulational instability is modified in a forced regime.
The wind can either damp the ocean wave amplitude when it blows slower or opposite to the propagation direction, or pump energy into the waves. Many experiments have been performed to investigate how surface waves and modulational instability are affected by wind and dissipation (Bliven *et al.* 1986, Waseda & Tulin 1999, Segur *et al.* 2005, Grare *et al.* 2013, Chabchoub *et al.* 2013) but the results are often in contradiction due to the difficulty of reducing the complexity of the interacting processes to simplified configurations. One can start by considering the simple framework where a quasi-laminar air flow interacts with a wave group that evolves under potential flow approximation. In this case the Miles mechanism provides the basis for energy exchange between wind and waves and the hydrodynamics equations can be handled analytically.
As in many complex systems, ocean waves are described as multi-scale processes. Thus the multi-scale method, where temporal and spatial scales for the envelope can be separated from the much smaller carrier-wave scales, can be used to introduce forcing and wave effects at the proper order (Brunetti *et al.* 2014). The main parameters are the steepness of the wave, ε, which is a measure of the degree of nonlinearity of the problem, and the Miles growth rate, Γ, which depends on the wind strength. The resulting forced NLSE has the following form (in normalized quantities, see Brunetti & Kasparian 2014):

$$i\frac{\partial A}{\partial t} - \frac{1}{2}\frac{\partial^2 A}{\partial x^2} - A|A|^2 = i\Gamma A + 3\Gamma\frac{\partial A}{\partial x} + \frac{1}{2}\Gamma^2 A$$

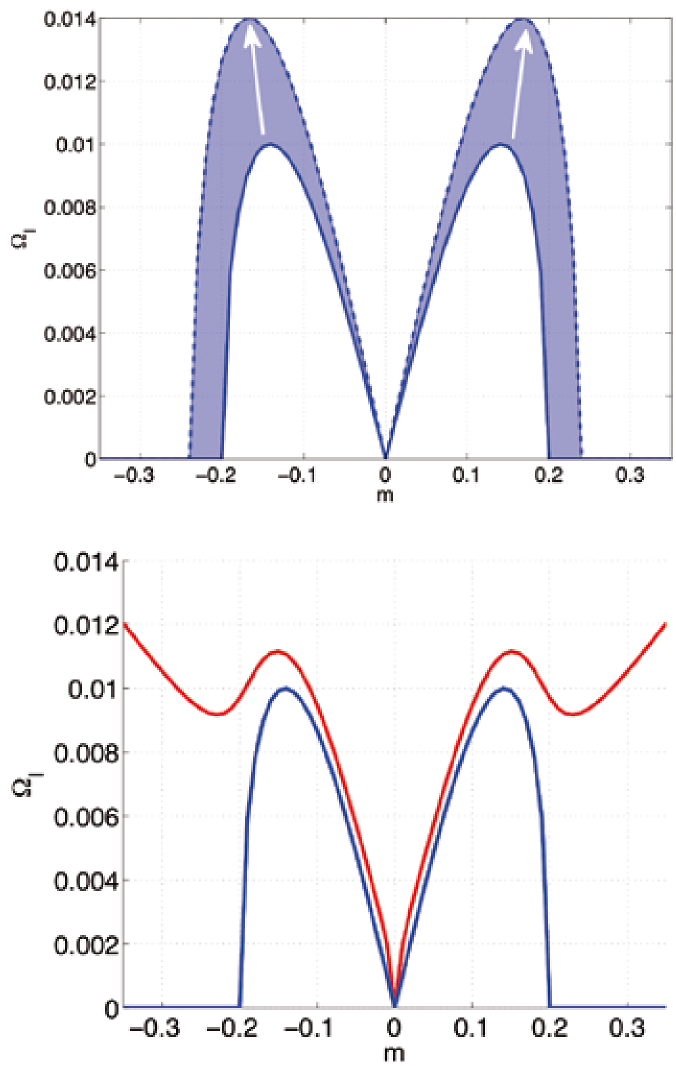


Figure 3. Effect of wind forcing on the gain band of the modulational instability. Top: in the case of slow wind (i.e. the (normalized) Miles growth rate Γ is much smaller than the wave steepness ε), the range of modulational wavenumbers m under the positive-gain band Ω_I increases in time. Bottom: in the case of strong wind, Γ ~ ε, the gain band is enhanced (red curve) with respect to the case without wind (blue curve) from the beginning.

It can be shown that the effect of the first term on the right-hand side is to increase in time the coefficient in front of the nonlinear term (Proment & Onorato 2012), while the effect of the last two terms on the right-hand side is to modify the dispersion term (Brunetti et al. 2014), thus wind affects the focusing process. The last two terms on the right-hand side disappear in the case of low Miles growth rates. In this regime of slow wind, the region of instability enlarges in time (Leblanc 2007), as shown by the shaded blue area in Fig. 3a. As a consequence, the range of modulational wavenumbers m within the positive-gain band Ω_I increases in time.
In the regime of strong wind, on the contrary, where the last two terms become dominant, the modulational instability is enhanced from the beginning, as shown by the position of the red curve in Fig. 3b (with respect to the blue curve which corresponds to the unforced regime). In this case, the gain band of the modulational instability has infinite width and thus induces a more important broadening of the initial spectrum with respect to the case of slow wind. This is a consequence that can be tested in air-sea interaction facilities such that installed at Pythéas-IRPHE/Luminy, Marseille (France), shown in Fig. 4.

Figure 4. Wind-wave facility at Pythéas-IRPHE in Marseille (France). Photo credit: Arthur Lemoine. The tank is 40 m long, 3 m wide and 0.9 m deep. It is equipped with a recirculating wind tunnel that can generate wind speeds between 1 and 14 m/s.

Experiments have been carried out this summer in the French facility, and preliminary results (Eeltink *et al.*, in prep.) show a series of interesting phenomena that need further investigation. The wind affects the energy spectrum in an asymmetric way and induces downshifting, i.e. the smaller sideband grows faster than the larger one. Downshifting can be also produced by dissipative effects (as wave breaking) or higher-order nonlinearities (because of the presence of odd-derivative terms, as in the Dysthe model). The difficulty in this kind of experiments is to find regimes where one process predominates, since due to the nonlinear dynamics of such systems it is not possible to completely isolate one process from the other. Numerical simulations and analogies between different domains are crucial to gain insight into these complex questions.

Acknowledgements

This work was partially supported by the Swiss National Science Foundation.

References

Akhmediev, N. N., Komeev, V., "Modulational instability and periodic solutions of the nonlinear Schrödinger equation", Theor. Math. Phys. **69**, 1089-1093 (1986).
Akhmediev, N. N., Soto-Crespo, J. M., Ankiewicz, A., "Extreme waves that appear from nowhere: in the nature of rogue waves", Phys. Lett. **A 373**, 2137-2145 (2009).
Ankiewicz, A., Soto-Crespo, J. M., Chowdhury, M. A., Akhmediev, N. N., "Rogue waves in optical fibers in presence of third-order dispersion, self-steepening, and self-frequency shift," J. Opt. Soc. Am. **B 30**, 87–94 (2013).
Armaroli, A., Conti, C., Biancalana, F., "Rogue solitons in optical fibers: a dynamical process in a complex energy landscape?", Optica **2**, 497-504 (2015).
Bergé, L., Skupin, S., Nuter, R., Kasparian, J., Wolf, J.-P., "Ultrashort filaments of light in weakly ionized, optically transparent media", Reports on Progress in Physics **70**, 1633-1713 (2007).
Bliven, L. F., Huang, N. E., Long, S. R., "Experimental study of the influence of wind on Benjamin-Feir sideband instability", Journal of Fluid Mechanics **162**, 237–260 (1986).
Brunetti, M., Marchiando, N., Berti, N., Kasparian, J., "Nonlinear fast growth of water waves under wind forcing", Phys. Letters **A 378**, 1025 (2014).
Brunetti, M., Kasparian, J., "Modulational instability in wind-forced waves", Phys. Letters **A 378**, 3626 (2014).
Chabchoub, A., Hoffmann, N., Branger, H., Kharif, C., Akhmediev, N., "Experiments on wind-perturbed rogue wave hydrodynamics using the Peregrine breather model", Physics of Fluids **25**, 101704 (2013).
Dysthe, K. B., "Note on a modification to the nonlinear Schrodinger equation for application to deep water waves" Proc. R. Soc. Lond. **A 369**, 105-114 (1979).
Dudley, J. M., Dias, F., Erkintalo, M., Genty, G., "Instabilities, breathers and rogue waves", Nature Photonics **8**, 755-764 (2014).
Eeltink, D., Branger, H., Lemoin, A. Brunetti, M., *et al.*, in preparation.
Erkintalo, M., Hammani, K., Kibler, B., *et al.*, "Higher-order modulational instability in nonlinear fiber optics", Phys. Rev. Lett. **107**, 253901 (2011).
Grare, L., Peirson, W. L., Branger, H., *et al.* "Growth and dissipation of wind-forced, deep-water waves", Journal of Fluid Mechanics **722**, 5–50 (2013).
Hadjihosseini, A., Peinke, J., Hoffmann, N. P., "Stochastic analysis of ocean wave states with and without rogue waves", New J. of Physics **16**, 053037 (2014).
Kharif, C., Pelinovsky, E., "Physical mechanisms of the rogue wave phenomenon", Eur. J. Mech. **B 22**, 603–34 (2003).
Kharif, C., Pelinovsky, E., Slunyaev, A., "Rogue Waves in the Ocean" (Berlin: Springer, 2009).
Kibler, B., Fatome, J. Finot, C., *et al.* "The Peregrine soliton in nonlinear fibre optics", Nature Physics **6**, 790-795 (2010).
Leblanc, S., "Amplification of nonlinear surface waves by wind", Phys. Fluids 19, 101705 (2007).
Mathis, A., Froehly, L., Toenger, S. *et al.* "Caustics and rogue waves in an optical sea", Scient. Rep. **5**, 12822 (2015).
Montina, A., Bortolozzo, U., Residori, S., Arecchi, F. T., "Non-Gaussian statistics and extreme waves in a nonlinear optical cavity" Phys. Rev. Lett. **103**, 173901 (2009).
Onorato, M., Proment, D., Phys. Lett. **A 376**, 3057-3059 (2012).
Onorato, M., Residori, S., Bortolozzo, U., Montina, A., Arecchi, F. T., "Rogue waves and their generating mechanisms in different physical contexts", Phys. Rep. **528**, 47–89 (2013).
Peregrine, D., "Water waves, nonlinear Schrödinger equations and their solutions", J. Austral. Math. Soc., Series B, **25**, 16-43 (1983).
Segur, H., Henderson, D., Carter, J., Hammack, J., *et al.*, "Stabilizing the Benjamin-Feir instability", Journal of Fluid Mechanics **539**, 229–271 (2005).
Solli D, Ropers, C., Koonath, P., Jalali, B., "Optical rogue waves", Nature **450**, 1054–1057 (2007).
Soto-Crespo, J. M., Grelu, P., Akhmediev, N. N., "Dissipative rogue waves: extreme pulses generated by passively mode-locked lasers", Phys. Rev. **E 84**, 016604 (2011).
Veldes, G. P., Borhanian, J., *et al.* "Electromagnetic rogue waves in beam-plasma interactions", J. Optics **15**, 064003 (2013).
Waseda, T., Tulin, M. P., "Experimental study of the stability of deepwater wave trains including wind effects", Journal of Fluid Mechanics **401**, 55–84 (1999).
Zakharov, V. E., Ostrovsky, L. A., "Modulational instability: the beginning", Physica **D 238**, 540-548 (2009).

Progress in Physics (51)

Will ultracold neutrons reveal their electric dipole moment?

Malgorzata Kasprzak, Uni Leuven, Belgium

Introduction

The neutron is a fermion with spin ½, but it is not an elementary particle; it consists of three valence quarks - two down quarks and one up quark. The three quarks, with their different fractional charges, are bound together by gluons and surrounded by the sea quarks. Although the neutron has no net electrical charge, the experimental data reveals that there is a charge distribution inside the neutron [1]. Moreover, despite its neutrality, the neutron possesses a magnetic moment. This phenomenon is to a certain extent explained by the quark model, introduced by Gell-Mann in 1964 [2], and confirmed by experimental results [3]. It is also interesting that the mass of the neutron m_n, which is 939.3 MeV/c^2, is only 0.14 % higher than the mass of the second nucleon, the proton. Calculations [4, 5] show that this difference is not only due to strong interactions between quarks, as described by quantum chromodynamics (QCD), but also due to the electromagnetic interaction, as modeled by quantum electrodynamics (QED). Different models, different approaches, huge efforts of experimental and theoretical physicists are being made to understand the structure of the neutron and of nucleons in general. The neutron in particular is not easy to examine due to both the lack of free neutron targets and also to the electric neutrality of the neutron, which rules out the possibility of accelerating them by means of electric fields. To understand the neutron structure and its implications for the physical laws governing the Universe, a family of experiments has been created wherein the neutron energy is extremely low – these neutrons are called ultracold neutrons (UCN). These experiments aim to tackle still unsolved issues such as with the neutron lifetime or with the permanent electric dipole moment of the neutron (nEDM). This article focuses on the properties of UCN, their production and application in the experimental quest for an nEDM.

Wave like nature of a neutron

UCN are neutrons with very low kinetic energies; typically $E_k = ½\, m_n v^2 < 300$ neV. They can be totally reflected from the surface of specific materials at all angles of incidence. This effect can be explained by analogy with the reflection of light. The neutron may be characterized by its de Broglie wavelength, $\lambda_n = h/m_n v$ (for UCN $\lambda_n > 80$ nm) where h is the Planck constant. Thus, the reflection of a neutron from a surface can be interpreted in terms of an index of refraction n given by:

$$n = \sqrt{1 - \frac{V(\vec{r})}{E_k}}$$

The term $V(\vec{r})$ in the above equation describes the interaction between the neutron and the matter. In the absence of interactions, $n = 1$. At the surface neutrons are affected by the so-called Fermi pseudo-potential V_F resulting from the coherent strong interactions with all the surface atoms' nuclei

$$V_F(\vec{r}) = \frac{h^2 b_{coh} N}{2\pi m_n}$$

where N is the number density of atoms and b_{coh} is the coherent scattering length of the material. Following Snell's law, we can define the critical incident angle θ_c above which total reflection occurs:

$$\sin\theta_c = n\ .$$

This can be further translated, for $\theta_c = 0$, into a critical velocity v_c, which determines the limit for the maximum velocity that UCN can have in order to be totally reflected:

$$v_c = \sqrt{\frac{2V_F}{m_n}}$$

Materials which are used in UCN physics are normally chosen to have large Fermi pseudo-potential, typically of the order of 10^{-7} eV, which corresponds to neutron velocities of up to ~ 5 m/s. For example, Be (V_F = 252 neV) and ^{58}Ni (V_F = 335 neV) are often incorporated as wall coatings in UCN equipment.

Figure 1. The interaction between neutron and atomic nuclei can be compared with a net stopping a football. Although the size of the neutron as a particle is 10^5 times smaller than the separation of atoms, its wavelength is larger than that spacing, resulting in the reflection of the neutron. However, in contrast to a football the interaction of the neutron with the surface is predominantly elastic and no lattice deformation occurs.

In a similar way we can look at the interaction of a neutron with magnetic fields, which can be described in terms of the potential energy given by the scalar product of the magnetic dipole moment $\vec{\mu}_n$ and the magnetic field $\vec{\mathbf{B}}$:

$$V_M\,(neV) = -\vec{\mu}_n \cdot \vec{\mathbf{B}} = \pm 60 B\,(T)$$

Just as for the nuclei of the material surface, the magnetic field creates a magnetic potential "wall" for the neutrons that have their magnetic moment antiparallel to the magnetic field lines, while pulling into the field the neutrons of the opposite orientation.

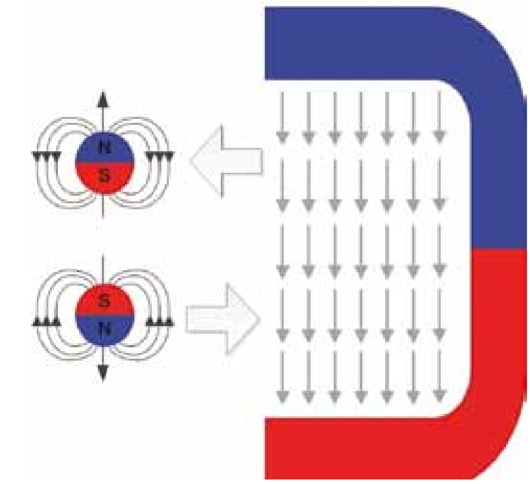


Figure 2. The neutron can be visualized as a small magnet and depending on its orientation is either attracted or repelled by the magnetic field gradient. UCN critical velocity, for which n = 0 is defined by $v_c = \sqrt{2V_M/m_n}$ *for magnetic moment antiparallel to the magnetic field lines. This effect is used in the storage of polarized UCN in magnetic bottles [6].*

Another unavoidable force acting on a free neutron comes from its interaction with gravity. According to classical mechanics, the neutron's potential energy in the terrestrial gravitational field is

$$V_g\,(neV) = m_n g H = 103\,H\,(m)\,,$$

implying that UCN with $E_k < 300$ neV in the Earth's gravitational field can rise to a maximum height H of about three meters. The sensitivity of UCN to gravitational effects is used in experimental studies of the laws of gravity and quantum mechanics by detecting quantum states of UCN in the Earth's field [7,8].

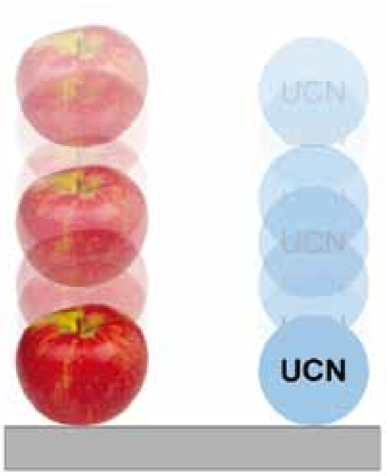


Figure 3. UCN experience free-fall under gravity very similarly to a falling apple. The energy of UCN in the Earth's gravitational field is quantized and the energy eigenstates have been observed experimentally [7]. The transitions between them are studied by gravity resonance spectroscopy testing the Newton's law of gravity [8].

It is clear from the above that UCN may be confined in traps. Such neutron "bottles" can be made of materials with high Fermi pseudo-potential. Alternatively they can use high magnetic fields of a few Tesla and its gradients to store the UCN. Combined magneto-material traps are also feasible. In the magnetic bottles only one spin state can be stored, while the non-magnetic material traps are spin independent. The optimal height of UCN storage volumes is determined by the gravitational effects, which shape the distribution of stored UCN [9]. Trapped UCN can also be considered as a non-interacting gas of about 3 mK temperature, according to $E_n = k_B T_n$, and as such be modeled. Interestingly, since the neutron-surface collisions are predominantly elastic, the UCN gas does not reach thermal equilibrium with the walls of the trap [10], and thus long storage times of UCN are readily achievable even at room temperature. Another factor enabling long observation times is the exceptionally long (for an unstable particle) neutron lifetime of 880.3(1.1) s [11], governed by weak interactions. Thus, stored UCN are an ideal system for high precision experiments such as searches for an electric dipole moment of the neutron, measurements of the neutron lifetime or studies of the neutron beta decay.

UCN production

Free neutrons produced either in nuclear or fission reactions have average energies of a few MeV, ten trillion times higher than UCN energies. The typical moderation process, based on elastic scattering with moderator molecules, is efficient until the neutrons reach thermal equilibrium with the medium, at an energy of ~ 25 meV in a room-temperature heavy-water moderator. To obtain UCN energies in such a way, one would need a large volume of non-absorbing material at about 4 mK temperature, which is not existing. Therefore, other cooling methods need to be applied, one of those being the so-called superthermal production [10]. In this process, the neutron energy is transferred not to a single molecule but rather to phonons, quasiparticles representing the collective motion of the atoms or molecules in for example a crystal lattice. The maximum possible energy transfer from neutrons to phonons is defined by the phonons' frequency spectrum.

In the UCN source [12] at the Paul Scherrer Institute (PSI), the phonon-based cooling of neutrons happens in solid deuterium at 5 K. The pulse of the proton beam from PSI's high intensity proton accelerator hits a lead target. The neutrons released in the spallation reaction are thermalized in heavy water and subsequently downscattered to ultracold neutron energies in a solid deuterium converter [13]. UCN are further transported with neutron guides to experiments, one of them being the search for the neutron EDM.

Electric Dipole Moment of a neutron

The possible existence of a neutron electric dipole moment has intrigued scientists since it was first suggested by Purcell and Ramsey in 1950 [15]. The reason for the ongoing interest is that the coexistence of the spin ½ and an electric dipole moment violates parity P symmetry (mirror reflection of physical processes) and time reversal invariance T (Fig. 5). Through the conservation of the combined symmetry CPT [16], it also violates CP symmetry (C being the charge conjugation operator replacing particles by their antiparticles). A violation of CP symmetry in the very early stages of the Universe is required to explain why there is almost no antimatter in our world. In the Big Bang scenario matter and antimatter should have been created in equal amounts from the primordial energy. The observed baryon to photon density ratio $\eta = n_B/n_\gamma \approx 6 \cdot 10^{-10}$ [11] indicates that in the early Universe the symmetries of the fundamental interactions were not conserved, leading to the observed dominance of

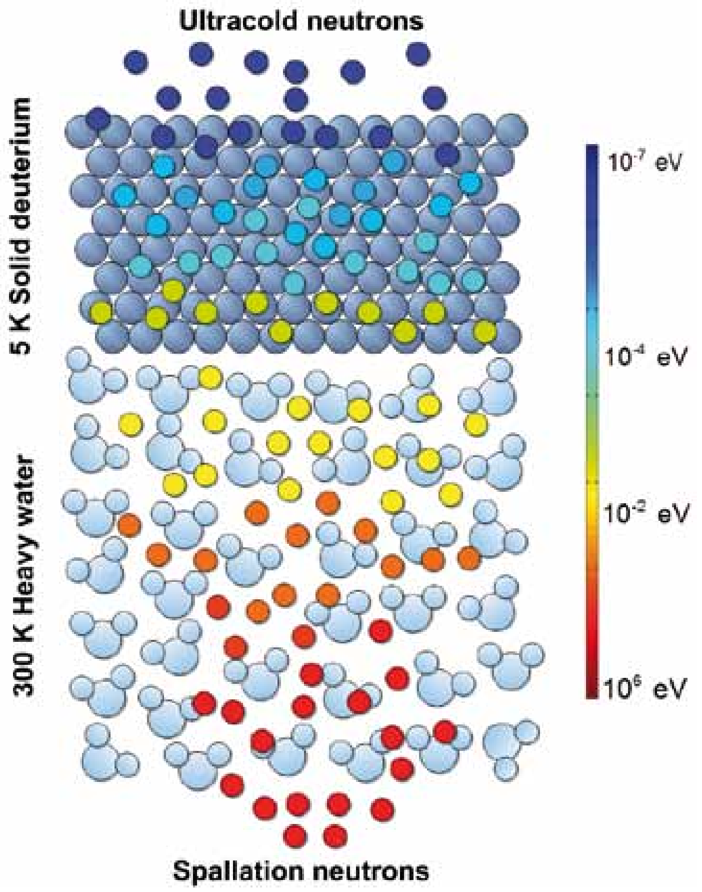


Figure 4. This picture illustrates the cooling process of fast neutrons in the PSI UCN source. Spallation neutrons with energies of few MeV are thermalized in heavy water and subsequently moderated in the solid deuterium at 5 K to cold neutron energies (meV). The last phase of neutron conversion takes place in the solid deuterium crystal where the cold neutrons are downscattered to ultracold neutron energies by transferring their momenta to phonons [14].

matter over antimatter. The explanation of the baryon asymmetry of the Universe requires, according to the criteria proposed by A. Sakharov [17], a source of CP-violation. A CP non-conserving mechanism, discovered in the neutral K meson decays [18], is implemented in the weak interaction sector of the Standard Model as a complex phase in the Cabbibo-Kobayashi-Maskawa quark mixing matrix. Based on this, the nEDM is calculated to be of order 10^{-32} e·cm [19], which is six orders of magnitude below the experimental upper limit of $3\cdot 10^{-26}$ e·cm [20] and far beyond the reach of currently running experimental efforts. On the other hand, the known (and parametrised) level of CP violation cannot account for the observed matter-antimatter asymmetry, so that other sources of CP violation have been postulated in different New Physics scenarios. A possible origin of CP violation in the Standard Model could arise in the strong interaction sector from non-perturbative QCD effects parametrized by the so-called Θ term [21]. Additional sources of CP violation are also proposed in different theories beyond the Standard Model (such as Supersymmetry) that attempt to quantitatively account for the matter-antimatter asymmetry. Most of these models provide theoretical predictions for nEDM values that are larger than 10^{-28} e·cm [22, 23], i.e. considerably larger than the value predicted by the Standard Model and potentially within the reach of experiments at proposed and running new UCN sources.

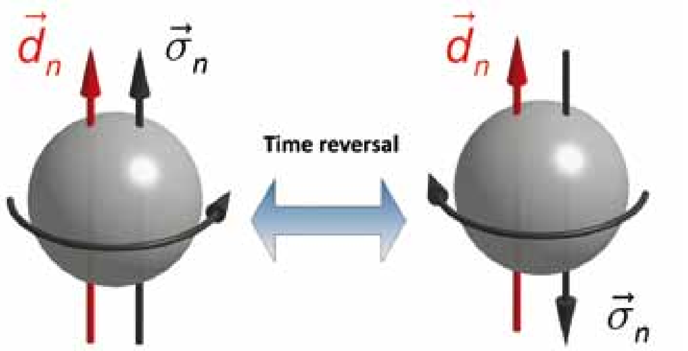


Figure 5. In a simplified interpretation the electric dipole moment can be pictured as separation of positive and negative electrical charges inside the neutron. The orientation of the neutron is specified only by its spin. The time reversal operation T, which changes the direction of the arrow of time, will not affect the charge distribution, but will reverse the neutron spin $\vec{\sigma}_n$, creating a different state for the time-reversed neutron.

With the development of UCN sources it has become possible to significantly increase the experimental nEDM sensitivity due to the ability to store UCN for hundreds of seconds. In the nEDM experiment [24] currently collecting data at the PSI, spin-polarized UCN from the PSI UCN source are trapped in a chamber and exposed to a static magnetic field B of 10^{-6} T, within which they undergo Larmor precession at a frequency $\nu_L \approx 30$ Hz. An nEDM signal would manifest itself via an increase or decrease of the neutrons' precession frequency ν_L induced by an electric field E of about 10 kV/cm, which is applied alternately parallel (ξ = +1) and anti-parallel (ξ = -1) to the static magnetic field:

$$h\nu_L^\xi = 2\vec{\mu}_n \cdot \vec{\mathbf{B}}_\xi + 2\xi\vec{d}_n \cdot \vec{\mathbf{E}}_\xi$$
$$\xi = \hat{E}\cdot\hat{B}$$

where $\mu_n \approx 6\times 10^{-8}$ eV/T is the magnetic dipole moment of the neutron. The presence of an nEDM (d_n) will manifest itself in a non-zero difference between the ξ = +1 and ξ = -1 configurations

$$\frac{h}{2E}(\nu_L^+ - \nu_L^-) = d_n + \mu_n\frac{B_+ - B_-}{2E}$$

A precise determination of the neutron spin precession frequency in the magnetic and electric fields is carried out using the Ramsey technique of (time-)separated oscillatory fields [25].

The interaction of the neutron's magnetic moment with the magnetic field (characterized by the Larmor frequency) is clearly, because of the smallness of d_n, orders of magnitude larger than the corresponding "electric" Larmor frequency describing the interaction of a possible electric dipole moment with the electric field. Therefore, any changes of the magnetic field have to be precisely known and controlled in order to sufficiently suppress any systematic effects associated with magnetic field drifts. Hence, the experiment is placed in a multi-layer magnetic shield. The Earth magnetic field and the time dependent ambient magnetic field are reduced and stabilized by actively controlled coils [26]. Residual magnetic field changes inside the shield are monitored by a Hg magnetometer [27] filling the same volume as the neutrons and by a laser-driven array of optically pumped Cs magnetometers [28] located below and above the neutrons' precession chamber. The Cs magnetometers, which were developed at the University of Fribourg, play an important role in the experiment not only because of the monitoring of the field distribution. They also allow the preparation of excellent homogenous magnetic field conditions.

Conclusions and outlook

Research with ultracold neutrons covers a broad range of topics, from neutron quantum optics to experiments searching for physics beyond the Standard Model of Particle Physics. UCN experiments are truly multidisciplinary; they encompass aspects of nuclear physics, condensed matter physics, atomic physics and particle physics. They allow probing fundamental questions concerning the matter-antimatter asymmetry of the Universe. The world-leading nEDM experiment located at the UCN source at the PSI is expected to improve over the best sensitivity by factor of two in the next 2-3 years. At the same time the nEDM collaboration is building a new apparatus. This new project is expected to be sensitive to an nEDM at the 10^{-27} e·cm level. With such improved sensitivity, either the nEDM will be found, or a new limit will set tight constraints on CP-violating physics beyond the Standard Model.

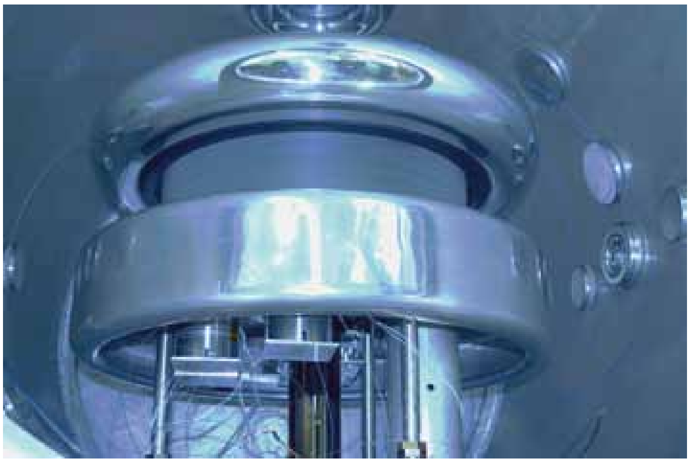


Figure 6. This photo of the nEDM experiment shows two aluminium electrodes encapsulating the UCN storage chamber. Below the lower (ground) electrode a number of Cs magnetometers are mounted. A second group of Cs magnetometers, fully optically coupled, is located on the upper (HV) electrode. With this configuration the spatial distribution of the magnetic field is continuously measured.

Acknowledgements

I would like to thank my colleagues; H. P. Beck, M. Daum, P. Harris, K. Kirch, B. Lauss, N. Severijns, A. Weis and G. Zsigmond for careful reading and corrections of the manuscript.

References

[1] G. A. Miller, *Charge Densities of the Neutron and Proton*, Phys. Rev. Lett. **99**, 112001 (2007)
[2] M. Gell-Mann, *A schematic model of baryons and mesons,* Phys. Lett. **8**, 214 (1964)
[3] S. Afach et al., *A measurement of the neutron to ^{199}Hg magnetic moment ratio*, Phys. Lett. **B 739**, 128 (2014) (nEDM collaboration)
[4] Sz. Borsanyi et al., *Ab inito calculation of the neutron-proton mass difference*, Science **347**, 1452 (2015)
[5] F. Wilczek, *A weighty mass difference*, Nature **520**, 303 (2015)
[6] D. J. Salvat et al., *Storage of ultracold neutrons in the magneto-gravitational trap of the UCNτ experiment*, Phys. Rev. **C 89**, 052501 (2014)
[7] V. V. Nesvizhevsky et al., *Quantum states of neutrons in the Earth's gravitational field*, Nature **415**, 297 (2002)
[8] T. Jenke et al., *Gravity resonance spectroscopy constrains dark energy and dark matter scenarios*, Phys. Rev. Lett. **112**, 151105 (2014)
[9] J. M. Pendlebury and D. J. Richardson, *Effects of gravity on the storage of ultracold neutrons*, Nucl. Instr. Meth. **A 337**, 504 (1994)
[10] R. Golub, D. Richardson, S. K. Lamoreaux, *Ultra-Cold Neutrons*, Adam Hiliger, Bristol, 1991.
[11] K. A. Olive et al. (Particle Data Group), Chin. Phys. C, **38**, 090001 (2014)
[12] B. Lauss, *Ultracold Neutron Production at the second spallation target of the Paul Scherrer Institute*, Phys. Proc. **51**, 98 (2014)
[13] F. Atchison et al., *Production of ultracold neutrons from cryogenic 2H_2, O_2, and C_2H_4 converters*, Eur. Phys. Lett. **95**, 12001 (2011)
[14] F. Atchison et al., *Cold Neutron Energy Dependent Production of Ultracold Neutrons in Solid Deuterium*, Phys. Rev. Lett. **99**, 262502 (2007)
[15] E. M. Purcell and N. F. Ramsey, *On the possibility of Electric Dipole Moments for Elementary Particles and Nuclei*, Phys. Rev. **78**, 807 (1950)
[16] G. Lüders, Proof of the TCP theorem, Ann. Phys. **281**, 1004 (2000)
[17] A. D. Sakharov, *Violation of CP invariance, C asymmetry, and baryon asymmetry of the universe*, Pis'ma Zh. Eksp. Teor. Fiz. **5**, 32 (1967)
[18] J. H. Christenson, J. W. Cronin, V. L. Fitch and A. Turlay, *Evidence for the 2π Decay of the K_2^0 Meson*, Phys. Rev. Lett. **13**, 138 (1964)
[19] A. Czarnecki and W. Marciano, *Electromagnetic Dipole Moments and New Physics*, In B. L. Roberts, W. J. Marciano "Lepton Dipole Moments", World Scientific Publishing (2010)
[20] J. M. Pendlebury et al., *A Revised Experimental Upper Limit on the Electric Dipole Moment of the Neutron*, arXiv:1509.04411, submitted to Phys.Rev. D
[21] R. J. Crewther et al., *Chiral estimate of the electric dipole moment of the neutron in quantum chromodynamics*, Phys. Lett. **B 88**, 123 (1979)
[22] M. Pospelov and A. Ritz, *Electric dipole moments as probes of new physics*, Ann. Phys. **318**, 119 (2005)
[23] J. Ellis et al., *A cosmological lower bound on the neutron electric dipole moment*, Phys. Lett. **B 99**, 101 (1982)
[24] C. A. Baker et al.,*The search for the neutron electric dipole moment at the Paul Scherrer Institute*, Phys. Proc. **17**, 159 (2011) (nEDM collaboration)
[25] N. F. Ramsey, *A Molecular Beam Resonance Method with Separated Oscillating Fields*, Phys. Rev. **78**, 695 (1950)
[26] S. Afach et al., *Dynamic stabilization of the magnetic field surrounding the neutron electric dipole moment spectrometer at the Paul Scherrer Institute*, J. Appl. Phys. **116**, 084510 (2014) (nEDM collaboration)
[27] C. A. Baker et al., *Apparatus for measurement of the electric dipole moment of the neutron using a cohabiting atomic-mercury magnetometer*, Nucl. Instr. Meth. **A 736**, 184 (2014)
[28] P. Knowles et al., *Laser-driven Cs magnetometer arrays for magnetic field measurement and control*, Nucl. Instr. Meth. **A 611**, 306 (2009)

Malgorzata Kasprzak received an MSc degree in Physics from Jagiellonian University in Krakow (PL) for her work on thermal up-scattering of very cold and ultracold neutrons. She continued this research during her PhD studies investigating neutron scattering and ultracold neutron production in cryogenic crystals. In 2008 she received a PhD degree in Physics from Vienna University (AT). Willing to understand more she decided to change her focus to atomic physics and joined the FRAP (Fribourg Atomic Physics) group at Fribourg University (CH), where she was studying the high resolution spectroscopy and optical detection of magnetic resonance. This resulted in the development of Cs sensors array for the nEDM experiment at the Paul Scherrer Institute. Presently she is working at the University of Leuven (BE) on the optimization of magnetometry for the nEDM project.

The 2015 Nobel Prize in Physics

André Rubbia, ETH Zürich

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2015 to **Takaaki Kajita**, Super-Kamiokande Collaboration, University of Tokyo, Kashiwa, Japan and **Arthur B. McDonald**, Sudbury Neutrino Observatory Collaboration, Queen's University, Kingston, Canada for "*the discovery of neutrino oscillations, which shows that neutrinos have mass*."

The Nobel neutrinos

In Zürich back in 1930, Wolfgang Pauli proposes as a "desperate remedy" the existence of a new neutral particle to explain the apparent energy and angular momentum non-conservation that was experimentally observed in radioactive decays of unstable isotopes. During the next few years, scientists including Enrico Fermi who invents the name "neutrino" for the small neutral particle, elaborate Pauli's theory and conclude that the new particle must be very weakly interacting and extremely light. The theoretical particle Pauli postulated had properties that made it so elusive that he even wondered whether anyone would ever observe it. In 1956 two American scientists, Frederick Reines and Clyde Cowan, report the first experimental evidence for the existence of neutrinos. They used a fission reactor as a powerful neutrino source and a well-shielded scintillator detector nearby to detect them. Reines would obtain in 1995 the Nobel Prize for "the detection of the neutrino". In 1962, a group from Columbia University and Brookhaven National Laboratory perform the first accelerator neutrino experiment and demonstrate the existence of two species of neutrinos, the electron neutrino and the muon neutrino. Leon M. Lederman, Melvin Schwartz and Jack Steinberger are jointly awarded the Nobel Prize in Physics in 1988 for "the neutrino beam method and the demonstration of the doublet structure of the leptons through the discovery of the muon neutrino". In 1975, a new charged lepton, the tau, is discovered by a group led by physicist Martin Perl at the Stanford Linear Accelerator Center, providing evidence that there should also exist a third species of neutrino, the tau neutrino.

While nuclear reactors and high-energy accelerators provide means to produce terrestrial neutrino beams, the Universe itself provides a natural laboratory to study cosmic neutrinos and with them the cosmos itself. The first detection of solar neutrinos by the Homestake experiment and that of neutrinos emitted by the SN1987A supernova by Kamiokande provided direct information on the physical processes that take place at the core of stars. In 2002, the Nobel Prize in Physics was awarded to Raymond Davis Jr. and Masatoshi Koshiba "for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos".

Discovery of neutrino masses and flavour oscillations

In 2015, we are honoured that a fourth Nobel Prize is awarded to neutrino physics for "the discovery of neutrino oscillations, which shows that neutrinos have mass." All direct attempts to measure the neutrino mass have given negative results, leading to upper limits for their masses. In the Standard Model of particle physics developed through the latter half of the 20th century, neutrinos were in fact assumed to be massless, consistent with experimental observations and the evidence that neutrinos produced in weak interactions are fully polarised (100% left-handed for neutrinos, and 100% right-handed for antineutrinos). Astrophysical observations also are consistent with neutrino masses below an electron-Volt (eV), much lighter than the charged leptons and the quarks.

In 1957, Bruno Pontecorvo, an Italian physicist living in the USSR, who had predicted that neutrinos associated with electrons are different from those associated with muons, formulates a theory of neutrino "oscillations". He shows that if different species of neutrinos exist and are produced and detected as "weak" eigenstates corresponding to linear combinations of "mass" eigenstates, they might be able to oscillate back and forth between different species via quantum mechanical interference. For instance, in the simplified case of only two neutrinos, the *appearance* probability for a neutrino of energy E produced with flavour "a" to be detected as flavour "b" at a distance L from its source is given by (see Figure 1)

$$P(\nu_a \rightarrow \nu_b) = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

where θ is the mixing angle, and $\Delta m^2 = m_2^2 - m_1^2$ is the difference of masses squared between the two neutrinos. This phenomenon requires the mass eigenstates to possess non-degenerate masses (i.e. a non vanishing Δm^2), hence the discovery of neutrino flavour oscillations indicates the finite mass of neutrinos and suggests to extend the Standard Model to include neutrino masses.

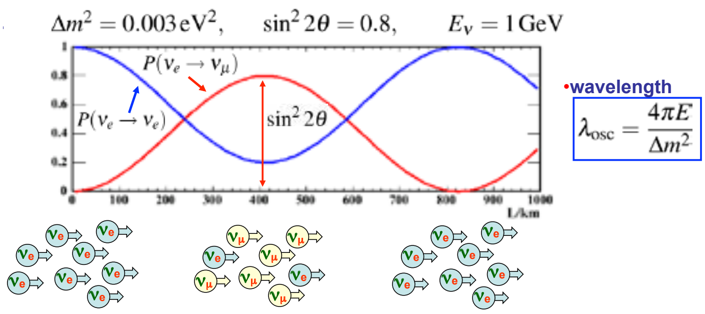


Figure 1 : Illustration of the electron neutrino oscillation probability as a function of the distance L between the source and the detector: (in red) the appearance of the muon flavour; (in blue) the disappearance of the electron flavour.

Although non-vanishing neutrino masses could have been in principle expected, their discovery came as a surprise. The first solar neutrino experiment Homestake was initiated to verify the nuclear reactions in the centre of the Sun. The

Kamiokande detector was built to search for the instability and measure the lifetime of protons to verify the predictions of Grand Unified Theories.

The Super-Kamiokande detector is an underground neutrino observatory located under Mount Kamioka in Japan. It consists of a cylindrical stainless steel tank about 40 m tall and 40 m in diameter holding 50,000 tons of ultra-pure water (see picture on the title page). Cherenkov light produced by elementary particles travelling faster than the speed of light in water has the shape of a cone (similar to an airplane traveling faster than the speed of sound) that is projected as a ring on the wall of the detector. This faint light is detected by 11,146 photomultiplier tubes (PMTs) surrounding the water volume. Each PMT has an impressive diameter of 50 cm (20 inches). Super-Kamiokande was the first detector large enough to study "atmospheric neutrinos" with high statistical precision. Atmospheric neutrinos are secondary cosmic rays produced by the decay of particles resulting from interactions of primary cosmic rays (mostly protons) with the Earth atmosphere. Using the timing and charge information recorded by each PMT, one can determine the energy, the direction and the flavour of the interacting neutrinos. In particular, electrons are distinguished from a muon from the sharpness of the edge of the Cherenkov ring. Interactions induced by electron- and muon-neutrinos produced in the atmosphere could therefore be separated and independently studied. In 1998, Takaaki Kajita at the Neutrino '98 conference in Japan [1], presented significant new data collected with Super-Kamiokande on the deficit of muon neutrinos [2] produced in the Earth's atmosphere: the number of upward going muon neutrinos (generated on the opposite side of the Earth) was about half of the number of downward going muon neutrinos. On the other hand, the flux of atmospheric neutrinos is predicted not to exhibit such particular asymmetry, since primary cosmic rays are isotropic with respect to the Earth (the Earth magnetic field influences this at low energies - an effect that can be calculated and is taken into account). Figure 2 shows the "up-down" asymmetry observed in Superkamiokande as a function of the visible momentum, which corresponds to the neutrino energy, for the events assigned to electrons and muons: while the electron sample is consistent with expectations, the muon sample displays a significant asymmetry. The observation could be explained if muon neutrinos changed or oscillated into some other neutrinos that were not detected. The data suggested that the deficit varies depending on the distance the neutrinos travelled before reaching the detector - an indication that neutrinos oscillate while they travel. A later analysis suggested a sinusoidal dependence of the event rate as a function of "Length/Energy", which is obtained for upward going muon neutrinos at various angles and thus varying distances travelled through the Earth's crust, and further confirmed the neutrino oscillation hypothesis.

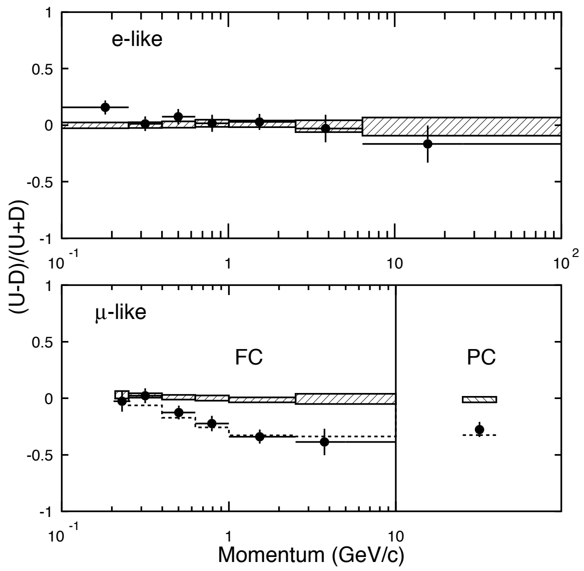


Figure 2: The observed "up-down" asymmetry as a function of momentum for electron-like events, and fully-contained (FC) and partially contained (PC) muon-like events. The expectation without neutrino oscillations is shown in the hatched region with statistical and systematic errors added in quadrature. The dashed line for muon-like is the expectation for $\nu_\mu \longleftrightarrow \nu_\tau$ oscillations with ($\sin^2 2\theta=1.0$, $\Delta m^2 = 2.2\times10^{-3}$ eV^2). From Superkamiokande [2].

The Sudbury Neutrino Observatory (SNO) located at 2100 m underground in a mine in Canada, was designed to detect solar neutrinos through their interactions with a large target tank filled with 1'000 tonnes of heavy water (D_2O). The detector cavity outside the vessel was filled with normal water to provide both buoyancy for the vessel and radiation shielding. The heavy water was viewed by approximately 9,600 PMTs mounted on a geodesic sphere at a radius of about 850 centimetres. The cavity housing the detector is the largest man-made underground cavity in the world, requiring a variety of high-performance rock bolting techniques to prevent rock bursts. Thanks to the heavy water

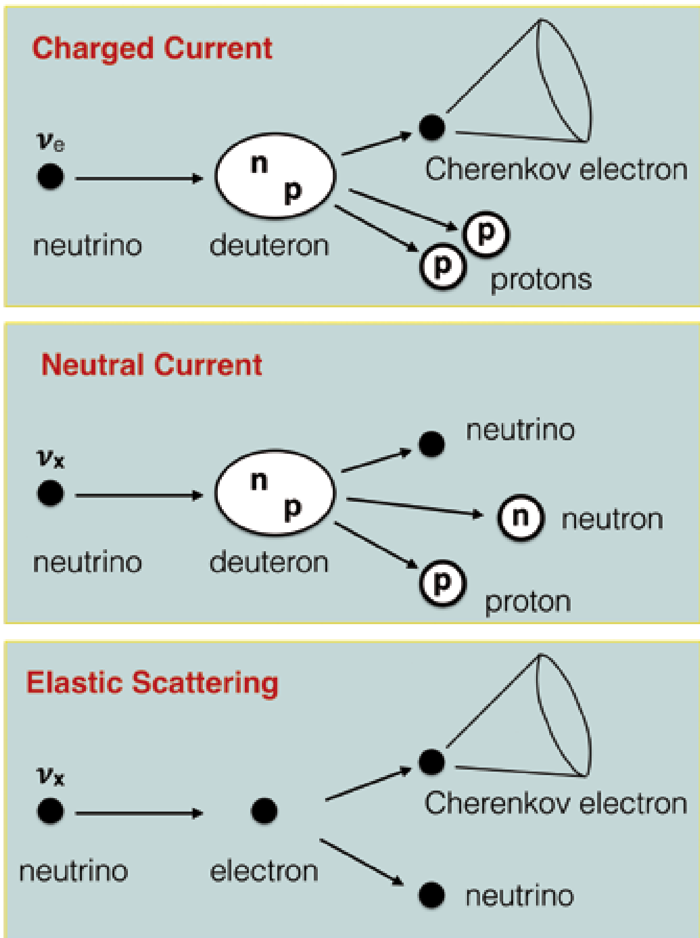


Figure 3: Unique signatures of neutrino interactions in the SNO heavy water target. From Art McDonald, "SNO and the new SNO-LAB", talk given at the Neutrino Telescopes International Conference, Venice 2007.

target, SNO was able to measure independently charged current, neutral current and elastic electron scattering interactions produced by solar neutrinos (see Figure 3). In the charged current interaction, a neutrino converts itself into a charged lepton and the neutron in the deuteron becomes a proton. Solar neutrinos have energies smaller than the mass of muons and tau leptons, so only electron neutrinos can participate in this reaction. The emitted electron carries off most of the neutrino's energy, and is detectable. In the neutral current interaction, a neutrino dissociates the deuteron into a proton and a neutron, and all three neutrino flavours are equally likely to participate in this interaction. The free neutron travels in the heavy water and thermalises and is eventually captured producing gamma rays which are detected. In the elastic scattering channel, the neutrino collides with an atomic electron and imparts some of its energy to the electron. All three neutrinos can participate in this interaction although with different probability: it is dominated by electron neutrinos. The scattered electrons point in the direction that the neutrino was travelling (away from the sun). Based on the detection of these reactions, SNO showed direct evidence [3,4] that the total flux of solar neutrinos of all flavours agreed well with the theoretical prediction of the Standard Solar Model, thereby proving that the deficit of solar neutrinos was due to the electron neutrino oscillating to a different flavour.

Chasing new discoveries

Past neutrino experiments have helped to establish the validity of the Standard Model of particle physics, the theoretical framework that provides our best explanation of the basic properties of matter. In the 90's, precision measurements from the LEP experiments at CERN showed that there can exist only three light species of neutrinos with the "standard" weak couplings predicted by the Standard Model.

Since neutrino masses and oscillations were revealed, a large number of experiments have been successfully built to investigate these in more detail and the Standard Model was extended to include these new observations. However, as always, these new insights led to further questions. Today, we have studied neutrino oscillations in great detail and understand them rather well. But one very important question remains: does the neutrino oscillate the same way as the anti-neutrino? Finding out that neutrinos oscillate differently to anti-neutrinos would have important consequences as it could help understand why our Universe is dominated by matter. Neutrinos, or more precisely their super-massive counterparts as predicted in the "see-saw" theory that explains why the observed neutrinos are so light, could be the clue to explain why in the Big Bang matter and anti-matter were created in equal measure, but the disintegration of these super-massive neutrinos has created the "left-over asymmetry" able to explain all the visible matter in the Universe.

Neutrinos could possibly also help explain other puzzling observations made by astrophysicists. Astrophysical observation have shown that there is much more matter in the Universe than we can directly observe, called Dark Matter. There is about five times more of Dark Matter than all ordinary matter. It was thought originally that the neutrinos could be a significant part of this Dark Matter, but we now know that they are not massive enough. The open question is: are there additional neutrinos that could explain Dark Matter? As a consequence of the LEP results, additional species of neutrinos, if they exist in Nature, must be "sterile". This is a speculative conjecture that is currently supported by some "anomalies" observed in accelerator experiments, although these do not apparently connect to the Dark Matter solution. At present, the existence of sterile neutrinos is still very controversial and inconclusive, however their existence is not excluded, and searches will continue.

Finally, the fundamental open question of the nature of the neutrino remains unanswered: all matter particles have anti-particles with opposite electric charge, but as the neutrino is electrically neutral, it is difficult to know what its anti-particle looks like. In fact neutrinos could be Majorana particles and thus neutrinos and anti-neutrinos could be the same particle (but still oscillate differently). The only way we currently know to determine the nature of neutrinos is to look for extremely rare nuclear "double-beta decays". Normally two neutrinos are produced in such decays, but new experiments are looking for "neutrino-less double-beta decays". This latter reaction, prohibited in the Standard Model, would be evidence for new physics and for neutrinos being Majorana particles.

In conclusion, neutrino physics continues to be a very lively and active field of particle physics. We can be sure that future neutrino experiments will promise not only to tell us more about the nature of the neutrino itself, but also to continue to illuminate the path toward new physics beyond the Standard Model. What constitutes Dark Matter, why the Universe has more matter than antimatter, and why are neutrinos so much lighter than other fundamental fermions, are some of the most important questions in particle physics today. If one could solve any one of those questions, it would be a major breakthrough. There is a world-wide race going on between many experiments to answer them: there are good reasons for the amazing neutrino to try to get (at least) one more Nobel !

References

[1] Takaaki Kajita, "Atmospheric neutrino results from Super-Kamiokande and Kamiokande — Evidence for ν_μ oscillations", Nuclear Physics B - Proceedings Supplements, Volume 77, Issues 1–3, May 1999, Pages 123-132, ISSN 0920-5632.

[2] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], "Evidence for oscillation of atmospheric neutrinos," Phys. Rev. Lett. **81**, 1562 (1998)

[3] Q. R. Ahmad *et al.* [SNO Collaboration], "Measurement of the rate of $\nu_e + d \rightarrow p + p + e^-$ interactions produced by 8B solar neutrinos at the Sudbury Neutrino Observatory," Phys. Rev. Lett. **87**, 071301 (2001) [nucl-ex/0106015].

[4] Q. R. Ahmad *et al.* [SNO Collaboration], "Direct evidence for neutrino flavor transformation from neutral current interactions in the Sudbury Neutrino Observatory," Phys. Rev. Lett. **89**, 011301 (2002) [nucl-ex/0204008].

European Energy Policy and Global Reduction of CO_2 emissions: Towards an effective sustainable electricity production in Europe

The Energy Group of the European Physical Society laid down in a basic document its position concerning a global energy strategy and the necessity of physical research to find reliable and effective solutions. This paper was discussed by the Swiss Physical Society (SPS) Board and also in a meeting in Lisbon, where two of its members, Christophe Rossel and Minh Quang Tran, attended. It includes concrete recommendations to the politicians. When formally issued, it was forwarded to the Federal Councillor, Mrs. Doris Leuthardt, head of the Federal Department of the Environment, Transport, Energy and Communication DETEC. In her answer, she noted with great interest the position paper and the need of the contribution from specialists from all fields to the change of our energy system. In particular, she is glad that our SPS is participating in the discussion of our country's energetic future.

Bernhard Braunecker

The Position of the Energy Group of the EPS

The forthcoming United Nations Climate Change Conference (Paris, December 2015) will be held with the objective of achieving a binding and global agreement on climate-related policy from all nations of the world. This conference, seeking to protect the climate, will be a great opportunity to find solutions in the human quest for sustainable energy as a global endeavour. The Energy Group of the European Physical Society (EPS) welcomes the energy policy of the European Union (EU) to promote renewable energies for electricity generation, together with energy efficiency measures. This policy needs to be implemented by taking into account the necessary investments and the impact on the economical position of the EU in the world. Since the direct impact of any EU energy policy on world CO_2 emissions is rather limited, the best strategy is to take the lead in mitigating climate change and in developing an energy policy that offers an attractive and economically viable model with reduced CO_2 emissions and lower energy dependence.

The Energy Group of the EPS has the following observations on the presently planned energy transformation in Europe:

(I) Europe alone cannot curb the increase in global CO_2 emissions. Global action is required.

The specific emissions due to power generation in Europe (352 g CO_2/kWh in 2011 [1]) are already only half as large as those in e.g. China and the EU contribution to the global CO_2 emissions is currently only about 11%. So, the recently proposed implementation [2] of the 2050 Energy Roadmap [3], aiming, inter alia, at a reduction by 40 to 50% in the total CO_2 emissions of the EU by 2030, would correspond to an estimated saving of a mere 4 to 5% in global CO_2 emissions [4], even after decades of enormous investments. The impact of reductions in CO_2 emissions in the EU will therefore remain marginal and will be massively over-compensated by rising emissions elsewhere, unless other nations contribute their share in reducing CO_2 emissions.

(II) An efficient expansion of renewable energy sources requires solutions for intermittency and storage.

The substantial CO_2 reductions recommended in the 2050 Energy Roadmap for the electrical power sector (as compared to 1990: a reduction of 57-63% by 2030 and 93-99% by 2050) implies a vast transformation of the existing power supply system in the EU (in which about 50% of the electricity production currently comes from fossil fuels) into either renewable or nuclear power or some combination. Already at the present level of penetration of renewables (~23% of the electricity production), solutions are urgently needed to tackle adequately the problem of intermittency. This will demand a combination of high capacity non-intermittent (e.g. nuclear, oil and coal fired) and flexible backup plants (e.g. gas, hydropower), large electrical energy storage capacities and substantial expansion of electricity distribution grids, including smart grids. Furthermore, the integration of this variable electricity supply is expected to become even more difficult as its percentage rises to above 30-40%. The expected change in the energy system is a colossal challenge (see e.g. [5]) and is expected to raise major technological and political issues requiring long-term perspectives and sustained investment in research and development.

(III) The EU energy policy ought to be framed to strengthen Europe's economic position in the world.

The level of subsidies for carbon-free energy sources ought to be set to assist in promoting the necessary research and to provide a competitive environment for developments in new energy technologies. Excessive subsidies are currently causing high electricity prices that are far beyond those in other regions of the world, contributing to the on-going relocation of industry from Europe into other regions of the world with less expensive energy. There is growing concern over the accelerating relocation from electricity intensive industries in the EU into countries with lower environmental standards [6], leading not only to increased European unemployment but also to increases in global greenhouse gas emissions.

(IV) Europe can lead the global effort in CO_2 reductions by proposing and demonstrating an attractive and economically viable model.

In Europe we are facing a global challenge that requires a multi-decade approach, going beyond the present "European Energy Transition Model". This will require a coherent and sustained energy policy that strengthens the mutually beneficial relationship between education, research and innovation.

The Energy Group of the EPS therefore recommends the following:

(1) A review of current electrical energy subsidies in the EU.

A review of current electrical energy regulations in Europe (subsidies, feed-in tariffs, etc.) is urgently needed and should focus on supporting the internal energy market in providing clean energy at competitive prices. This implies in particular enhanced efforts in research and innovation for sustainable energy technologies.

(2) The inclusion of external costs when pricing electricity from all supply options.

The cost of various electricity production options should be correctly quantified by taking into account external costs, including an adequate carbon price, costs linked to societal and health risks and the additional costs inherent in the use of large amounts of intermittent power generation. This last point will become very important when implementing the 2050 Energy Roadmap, as it will be essential to have parallel development programmes for energy storage technologies (batteries, power-to-gas, etc.), back up power solutions, upgrades of distribution grids including smart grid technologies and energy efficiency measures (heating, cooling, light, …).

(3) An increase in R&D funding for sustainable technologies with a focus on developing an effective and economically viable low carbon electricity system.

R&D in improved technologies for the electricity sector together with Carbon Capture and Storage is a key to achieving a sustainable electricity future. The return on this investment will be a competitive advantage in the rapidly growing world market for sustainable technologies.

(4) Consideration of all non-fossil electricity options when discussing the EU energy future.

The present focus on the deployment of intermittent renewables should be complemented by developing and implementing other low carbon options, which are able to provide base load and dispatchable power to the grid (such as second generation biomass, geothermal, nuclear fission at present and fusion in the longer term). The objective should be to provide a balanced energy mix, which is economically optimized and ensures security and diversity of supply. Although the present policies on nuclear fission differ in individual EU countries, this option and the related know-how, remains globally important. An adequate level of research and technological competence must be maintained to keep open the option of building next generation fission reactors, in addition to fusion technology at a later stage.

(5) Negotiation of a global agreement for a reduction in worldwide CO_2 emissions.

The implementation of a globally relevant and economically viable future energy policy, agreed upon by all European nations, will strengthen the position of Europe as a leading party in on-going international negotiations towards a worldwide agreement on reducing global CO_2 emissions, together with other major greenhouse gases. Global emission reductions can only be achieved if all nations in the world assume their responsibility for mitigating greenhouse gas emissions.

(6) A revisit of the 2050 Energy Roadmap.

What is needed is a Roadmap that not only sets targets with defined dates in terms of amounts of installed electrical power, energy production and demand and emission reductions, but also takes into account technology development times, safety and socio-economic aspects of various energy technologies. As low carbon options become more competitive, the choice of the technology mix should increasingly be left to the market, taking into account national and regional differences.

(7) Fostering scientifically and factually based educational programmes for students and the general public on energy use and energy technologies.

The EPS calls for discussions on the EU Energy Policy and on these recommendations in all relevant contexts. The EPS also encourages strengthening the voice of scientific and technical knowledge in the field of energy, with the aim of assisting in the definition of a far-sighted and effective energy policy.

References:

[1] CO_2 Emissions from fuel combustion, Highlights, IEA Statistics, 2013 Edition
[2]"A policy framework for climate and energy in the period 2020 to 2030", COM(2014) 015, EC Brussels, 22 Jan 2014
[3] "Energy Roadmap 2050", COM(2011) 885, EC Brussels, 15 Dec 2011
[4] EDGAR, Emission Database for Global Atmospheric Research, (http://edgar.jrc.ec.europa.eu)
[5] F. Wagner, "Considerations for an EU-wide use of renewable energies for electricity generation", Eur. Phys. J. Plus (2014) 129: 219
[6] "Resolution and Report on renewable energies and economic competitiveness", EEA Consultative Committee, Ref. 1130862, Oslo, 8 May 2014; "Impact of energy and feedstock costs on the competitiveness of the chemical industry in the ARA-cluster", Essenscia, Brussels, 8 May 2014; "Development and integration of renewable energy: Lessons learned from Germany", Finadvice, Aldiswil, June 2014.

History of Physics (14)

At the end of the International Year of Light IYL2015 of the UNESCO we would like to remember one of the pioneers of modern optics, Max Born. Based on his *Optik* from 1933, Born and his assistant Emil Wolf published 1959 the *Principles of Optics, Electromagnetic Theory of Propagation, Interference and Diffraction of Light*, even today one of the most read monographies in optics. They did not only describe the known physics of light at that time in a rigorous, elegant mathematical diction, but also worked out visionarily the basics of modern photonics, i.e. the important role of coherence functions and their propagation. It was more than a lucky coincidence that only one year later after their *opus magnum* was published, the laser was invented (1960). This nearly simultaneous appearance of the theory of coherent light sources and its hardware realization was a major reason to catapult optics to its modern variant, the photonics. We are very happy that Emil Wolf allowed us to reprint his memories of the history of *the* 'Born & Wolf'.

Bernhard Braunecker

Recollections of Max Born

Emil Wolf
Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627 USA

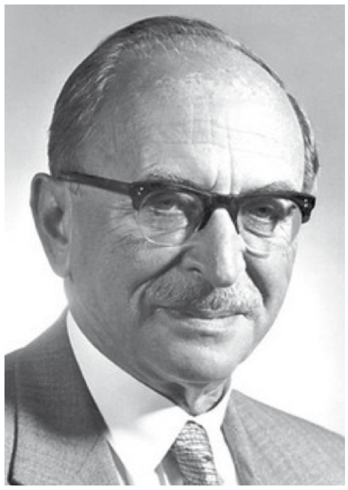
Abstract. This article is essentially the text of lectures presented September 7, 1982 at the Max Born Centenary Conference held in Edinburgh, Scotland and October 21, 1982 at the Max Born Symposium held during the Annual Meeting of the Optical Society of America.

1 Introduction

The invitation to address this commemorative meeting has given me the rare opportunity to set aside my customary activities and try to recall a period of my life several decades ago when I had the great fortune of being able to collaborate with Max Born. As the title of my talk suggests, this will be a rather personal account, but I will do my best to present a true image of a scientist who has contributed in a decisive way to modern physics in general and to optics in particular; it will also present glimpses of a man who, under a somewhat brusque exterior, was a very humane and kind person and who in the words of Bertrand Russell was brilliant, humble, and completely without fear in public utterances.

The early part of my story is closely interwoven with another great scientist, Dennis Gabor, through whose friendship I became acquainted with Born.

I completed my graduate studies in 1948 at Bristol University. My PhD thesis supervisor was E. H. Linfoot, who at just about that time was appointed Assistant Director of the Cambridge University Observatory. He offered me, and I accepted, a position as his assistant in Cambridge. During the next two years while I worked in Cambridge I frequently travelled to London to attend the meetings of the Optical Group of the British Physical Society. They were usually held at Imperial College and were often attended by Gabor, whose office was in the same complex of buildings. From time to time I presented short papers at these meetings. At the end of some of the meetings Gabor would invite me to his office for a chat. He would comment on the talks, make suggestions regarding my work, and speak about his own researches. Gabor liked young people, and he always offered encouragement to them. He knew Born from Germany, and he had great admiration for him.



Dennis Gabor

Through Gabor I learned in 1950 that Born was thinking of preparing a new book on optics, somewhat along the lines of his earlier German book *Optik*, published in 1933, but modernized to include accounts of the more important developments that had taken place in the nearly 20 years that had gone by since then. At that time Born was the Tait Professor of Natural Philosophy at the University of Edinburgh, a post he had held since 1936, and in 1950 he was 67 years old, close to his retirement. He wanted to find some scientists who specialized in modern optics and who would be willing to collaborate with him in this project. Born approached Gabor for advice, and at first it was planned that the book would be written jointly by him, Gabor, and H. H. Hopkins. The book was to include a few contributed sections on some specialized topics, and Gabor invited me to write a section on diffraction theory of aberrations, a topic I was particularly interested in at that time. Later it turned out that Hopkins felt he could not devote adequate time to the project, and in October of 1950, Gabor, with Born's agreement, wrote to Linfoot and me asking if either of us, or both, would be willing to take Hopkins' place. After some lengthy negotiations it was agreed that Born, Gabor, and I would co-author the book.

2 The start of collaboration

I was, of course, delighted with this opportunity, but there was the problem of my finding the necessary time to work on this project while holding a full-time appointment with Linfoot at Cambridge. I mentioned this to Gabor, and I told him that if there were any possibility of obtaining an appointment with Born, which would allow me to spend most of my time working on the book, I would gladly leave Cambridge and go to Edinburgh.

Gabor took up the matter with Born, who was interested. Toward the end of November 1950, Gabor wrote me that Born would be in London a few days later and that he (Gabor) was arranging for the three of us to meet the following weekend. It was agreed that I would come to Gabor's office at Imperial College on the following Saturday morning, December 2, 1950, and that we would then go to his home in South Kensington, within walking distance of Imperial College. Born was to come directly to Gabor's home from his London hotel, and the three of us and Mrs. Gabor would have lunch there.

I arrived at Gabor's office just before lunch, and I have a vivid recollection of that meeting. There was a long staircase leading to the entrance hall of the building. As we were walking down the staircase, Gabor suddenly became somewhat apprehensive. He knew that our luncheon meeting might lead to an appointment for me with Born, and he said to me, "Wolf, if you let me down, I will never forgive you. Do you know who Born's last assistant was? Heisenberg!" This statement was not accurate. Born had other assistants after Heisenberg, but the remark shows how nervous Gabor was on that particular occasion. Fortunately, all turned out well, and Gabor certainly seemed in later years well satisfied with the consequences of our luncheon with Born.

During that meeting Born asked me a few questions, mainly about my scientific interests, and before the lunch was over he invited me to become his assistant in Edinburgh, subject to the approval of Edinburgh University. It seemed to me remarkable that Born should have made up his mind so quickly, without asking for even a single letter of reference, especially since I had published only a few papers by that time and was quite unknown to the scientific community.

Later, when I got to know Born better, I realized that his quick decision was very much in line with one trait of his personality; he greatly trusted the judgment of his friends. Since Gabor recommended me, Born considered further inquiries about me to be superfluous. Unfortunately, as I also learned later, Born's implicit trust in people whom he considered to be his friends was occasionally misplaced and sometimes created problems for him.

A few days after our meeting I received a telegram from Born inviting me to a formal interview at Edinburgh University. The interview took place about two weeks later, and the next day Born wrote me saying that the committee which interviewed me recommended my appointment as his private assistant, beginning January 23, 1951. I resigned my post in Cambridge and took up the new appointment. Later I learned that committee approval was not really needed because my salary was to be paid from an industrial grant that was entirely at Born's disposal. However, on this occasion Born was careful, because some time earlier he had had on his staff Klaus Fuchs, who turned out to be a spy for the Russians, and Born got rather bad publicity from that.

Now, the name Fuchs means fox in German, and before inviting me to Edinburgh, Born apparently wrote to Sir Edward Appleton, the Principal of Edinburgh University at that time, saying that he felt the decision about this particular appointment should not be made by him alone; since he would like to appoint a Wolf after a Fox!

3 Arrival at Edinburgh

I arrived in Edinburgh toward the end of January 1951, eager to start on our project. Born's Department of Applied Mathematics was located in the basement of an old building on Drummond Street. I was surprised by the small size of the department. Physically it consisted of Born's office; an adjacent large room for all of his scientific collaborators, about five at that time; a small office for Mrs. Chester, his secretary; two rooms for the two permanent members of his academic staff, Robert Schlapp, a senior lecturer, and Andrew Nisbet, a lecturer; and one lecture room. The rest of the building was occupied by experimental physicists under the direction of Professor Norman Feather. In earlier days the building housed a hospital, in which Lord Lister, a famous surgeon known particularly for his work on antiseptics, also worked.

In spite of his advanced age Born was very active and, as throughout all his adult life, a prolific writer. He had a definite work routine. After coming to his office he would dictate to his secretary answers to the letters that arrived in large numbers almost daily. Afterward he would go to the adjacent room where all his collaborators were seated around a large U-shaped table. He would start at one end of it, stop opposite each person in turn, and ask the same question: "What have you done since yesterday?" After listening to the answer he would discuss the particular research activity and make suggestions. Not everyone, however, was happy with this procedure. I remember a physicist in this group who became visibly nervous each day as Born approached to ask his usual question, and one day he told me that he found the strain too much and that he would leave as soon as he could find another position. He indeed did so a few months later. At first I too was not entirely comfortable with Born's question, since obviously when one is doing research and writing there are sometimes periods of low productivity. One day when Born stood opposite me at the U-shaped table and asked, "Wolf, what have you done since yesterday?" I said simply "Nothing!" Born seemed a bit startled, but he did not complain and just moved on to the next person, asking the same kind of question again.

Born was always direct in expressing his views and feelings, but he did not mind if others did the same, as this small incident indicates. There will be more examples of this later.

4 Work at Edinburgh

We started working on the optics book as soon as I came to Edinburgh. It was understood right from the beginning that Born's main contribution would consist of making material available from his German *Optik*, but he was to take part in the planning of the new book, make suggestions, and provide general advice. Most of the actual writing was to be done by Gabor and me and a few contributors. However, like Hopkins earlier on, Gabor soon found it difficult to devote the necessary time to the project, and it was mutually agreed that he would not be a co-author after all, but would just contribute a section on electron optics. So in the end it became my task to do most of the actual writing. Fortunately I was rather young then, and so I had the energy needed for what turned out to be a very large project. I was in fact 40 years younger than Born. This large age gap is undoubtedly responsible for a question I am sometimes asked, whether I am a son of the Emil Wolf who co-authored *Principles of Optics* with Max Born!

Although I did most of the writing, Born read the manuscript and made suggestions for improvements. We signed a contract with the publishers about a year after I came to Edinburgh, and we hoped to complete the manuscript by the time Born was to retire, one-and-a-half years later. However, we were much too optimistic. The writing of the book took about eight years altogether.

Throughout his life Born was a quick, prolific writer, publishing more than 300 scientific papers, about 31 books (not counting different editions and translations), apart from numerous articles on nonscientific topics. In spite of my relative youth I could not compete with the speed with which Born wrote, even at his advanced age, and it soon became clear to me that he was not too pleased with my slow progress.

One day when I started writing an Appendix on Calculus of Variations, Born said that the best treatment of that subject he knew of was in his notes of lectures given by the great mathematician David Hilbert in Göttingen in the early years of this century. Born suggested that he dictate the Appendix to me, following in the main Hilbert's presentation, and that we acknowledge this in the preface to our book. So we started in this way. After each dictating session I was to rewrite the notes and give them to Born the next day for his comments. But we did not get very far this way. After about two dictating sessions Born said he could prepare the whole Appendix himself much faster without my help, which he then did. It is essentially in this version, written by Born, that the Appendix on Calculus of Variations appears in our book.

5 Born's revered teacher

Incidentally, David Hilbert, whose presentation Born closely followed, was one of Born's great heroes. To physicists Hilbert is mainly known in connection with the concept of the Hilbert space and as co-author of the classic text *Methods of Mathematical Physics*, referred to generally as "Courant-Hilbert". But Hilbert contributed in a fundamental way to many branches of mathematics and was generally considered to have been the greatest mathematician of his time. Born became acquainted with Hilbert soon after coming to Göttingen in 1905, later becoming Hilbert's private assistant. In one of his later writings Born refers to Hilbert as his "revered teacher and friend", and in a biography of Hilbert by Constance Reid (Reid, 1970), Born is quoted as saying that his job with Hilbert was to him "precious beyond description because it enabled [him] to see and talk to him every day".

David Hilbert, 1912

Born had an encyclopedic knowledge of physics and whatever problem one brought to him, he was able to offer a useful insight or suggest a pertinent reference. He also knew personally all the leading physicists of his time and would often recall interesting stories about them.

Optics in those days -remember we are talking about optics in pre-laser days- was not a subject that most physicists would consider exciting; in fact, relatively little advanced optics was taught at universities in those days. The fashion then was nuclear physics, particle physics, high energy physics, and solid state physics. Born was quite different in this respect from most of his colleagues. To him all physics was important, and rather than distinguish between "fashionable" and "unfashionable" physics he would only distinguish between good and bad physics research.

Born was equally broad-minded about the techniques used by physicists in their research. For example, when we were writing a section on certain mathematical methods needed to evaluate the performance of optical systems, we found that although the results given in a basic paper on this subject were correct, the derivation contained serious flaws. I was rather indignant about this, but Born just said something like, "In pioneering work everything is allowed, as long as one gets the right answer. Real justification can come later."

One of the earliest occasions when many physics students encounter Born's name comes when they start studying quantum theory of scattering. Here they soon learn about the *Born approximation*. This term also occurs in many of the papers on potential scattering that have been published in the more than half a century that has gone by since Born wrote a basic paper on this subject. Yet Born was rather irritated when the Born approximation was mentioned. He once said to me, "I developed in that paper the whole perturbation expansion for the scattered field, valid to all orders, yet I am only given credit for the first term in that series!"

6 Resistance to new discoveries

It was not always easy for Born's collaborators to convince him quickly of new discoveries. Let me illustrate this by an example from my own experience. In the early 1950s I became very interested in problems of partial coherence. One day I found a result in this area of optics that seemed to me remarkable. I phoned Born from my home one morning, told him I had an exciting new result, and asked him for an appointment to discuss it. We arranged to have lunch together that day.

When I came to his office just before lunch, Born wanted to know straight away what the excitement was all about. I told him I had found that not only an optical field, but also its coherence properties, characterized by an appropriate correlation function (now known as the mutual coherence function), are propagated in the form of waves. Born looked at me rather skeptically, put his arm on my shoulder and said, "Wolf, you have always been such a sensible fellow, but now you have become completely crazy!" Actually after a few days he accepted my result, and I suspect he then no longer doubted my sanity.

This incident illustrates a fact well known to Born's collaborators - that Born had a certain resistance to accept new results obtained by others. Nonetheless, he continued thinking about them, and if they were correct he would eventually apologize for doubting them in the first place.

This trait of Born's personality is very well described by the Polish physicist Leopold Infeld, who collaborated with Born in Cambridge in the 1930s. I will quote shortly some very perceptive observations Infeld made about Born in his biography (Infeld, 1941); but before doing so I would like to mention a small incident relating to this book.

One day I browsed through a bookstore in Edinburgh and found a used copy of Infeld's book. I was astonished to note that the book had Born's signature on its first page. I purchased it and asked Born the next day wether he knew the book. He said, 'Yes, I had a copy of it and there is a funny description of me in it; but I lent it to someone and it was never returned. I cannot remember whom I lent it to." The book I had purchased was obviously Born's missing copy, so I gave it to him, much to his delight.

In the book Infeld describes some of his experiences in Cambridge. He started working with Dirac but found him rather uncommunicative. Later Infeld attended some of Born's lectures. During one of them Born gave an account of some results that he had recently obtained. Infeld could not understand one of Born's arguments. He borrowed his notes so that he could study the argument more closely later. Let me now quote from Infeld's biography (Infeld, 1947, p.208 *et seq*):

On the evening of the day I received the paper the point suddenly became clear to me. I knew that the mass of the electron was wrongly evaluated in Born's paper and I knew how to find the right value. My whole argument seemed simple and convincing to me. I could hardly wait to tell it to Born, sure that he would see my point immediately. The next day I went to him after his lecture and said: "I read your paper; the mass of the electron is wrong." Born's face looked even more tense than usual. He said: "This is very interesting. Show me why." Two of his audience were still present in the lecture room. I took a piece of chalk and wrote a relativistic formula for the mass density. Born interrupted me angrily: "This problem has nothing to do with relativity theory. I don't like such a formal approach. I find nothing wrong with the way I introduced the mass." Then he turned toward the two students who were listening to our stormy discussion. "What do you think of my derivation?" They nodded their heads in full approval. I put down the piece of chalk and did not even try to defend my point. Born felt a little uneasy. Leaving the lecture room, he said, "I shall think it over."

Infeld then goes on to say:

I was annoyed at Born's behavior as well as at my own and was, for one afternoon, disgusted with Cambridge. I thought: "Here I met two great physicists. One of them does not talk. I could as easily read his papers in Poland as here. The other talks, but he is rude." The next day I went again to Born's lecture. He stood at the door before the lecture room. When I passed him he said to me. "I am waiting for you. You were quite right. We will talk it over after the lecture. You must not mind my being rude. Everyone who has worked with me knows it. I have a resistance against accepting something from outside. I get angry and swear but always accept it after a time if it is right". Our collaboration had begun with a quarrel, but a day later complete peace and understanding had been restored.

A little further on in his biography, Infeld speaks about Born again, and this is what he says:

I marveled at the way in which he managed his heavy correspondence, answering letters with incredible dispatch, at the same time looking through scientific papers. His tremendous collection of reprints was well ordered; even the reprints from cranks and lunatics were kept, under the heading "Idiots". Born functioned like an entire institution, combining vivid imagination with splendid organization. He worked quickly and in a restless mood. As in the case of nearly all scientists, not only the result was important but the fact that he had achieved it.

Infeld later continues:

There was something childish and attractive in Born's eagerness to go ahead quickly, in his restlessness and his moods, which changed suddenly from high enthusiasm to deep depression. Sometimes when I would come with a new idea he would say rudely, "I think it is rubbish," but he never minded if I applied the same phrase to some of his ideas. But the great, the celebrated Born was as happy and as pleased as a young student at words of praise and encouragement. In his enthusiastic attitude, in the vividness of his mind, the impulsiveness with which he grasped and rejected ideas, lay his great charm.

I regard these remarks of Infeld as a true and very perceptive description of Born's mode of work and of Born's personality.

7 Kind and compassionate

In spite of Born's occasional irritation and impatience, he was a person who cared deeply for the well-being of his fellow scientists and collaborators. His wife, Hedwig Born, was likewise a person with deep compassion for others. She too was a remarkable and gifted person. Mrs. Born published a number of books, especially poetry, and around 1938 became a Quaker, remaining active in the Quaker movement for the rest of her life.

I would like to give just one example from my own experience, which illustrates Born's concern for others. A few months after I began working with Born, I was getting married. In those days it was difficult to rent an apartment in Edinburgh. One day during the time when

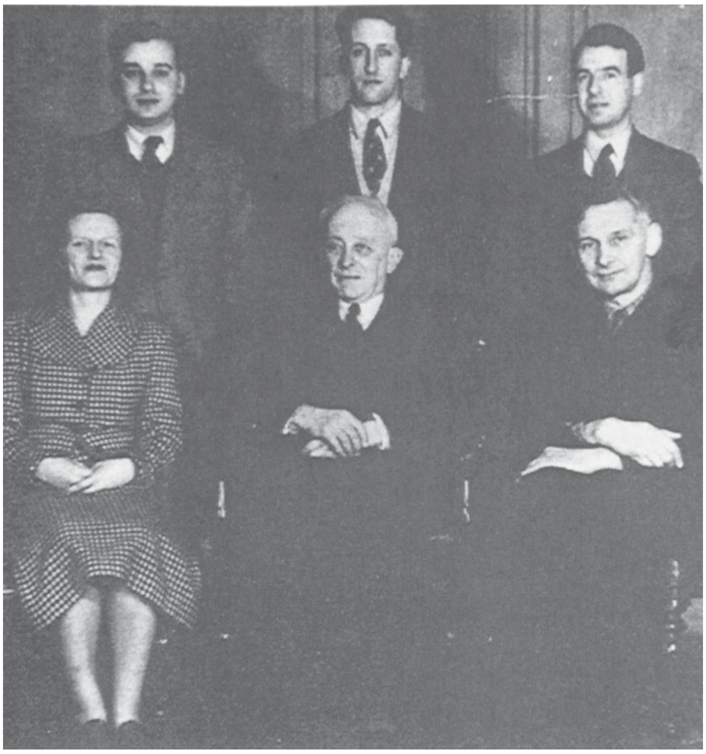
"In an Age of mediocrity and moral pygmies, the lives of Albert Einstein and Max Born shine with an intense beauty. Something of this is reflected in their correspondence, and the world is the richer for its publication."

(From Bertrand Russell's Foreword to *The Born - Einstein Letters*.)

we were searching for a home I received a letter from Mrs. Born, who was then with Professor Born on a visit to Germany. She said that they had heard about our problem and were very concerned that we might have to postpone getting married if we did not find somewhere to live. She then offered to help us, suggesting that we share with them their small house in Edinburgh. In the end we found an apartment elsewhere; but this small episode is an indication of the warmth of their personalities and of their willingness to make a personal sacrifice to help, when help was needed.

I mentioned earlier, that one of Born's great heroes was the mathematician David Hilbert. But there was another, even greater hero in Born's life: Albert Einstein, with whom he and also Mrs. Born maintained close personal friendships for almost half a century. Unfortunately, after Einstein left Europe for America in 1932 they did not see each other again, but they carried on extensive correspondence until Einstein's death in 1955. The letters they exchanged were published in 1971, together with Born's commentary, and the volume (Born, 1971) is a precious contribution to the history of physics and of the times in which they lived.

There is an episode I would like to relate briefly in connection with Born's friendship with Einstein. In the early 1950s, when Sir Edmund Whittaker was preparing the second volume of his classic work *A History of the Theories of Aether and Electricity*, he sent Born the manuscript of a section dealing with the special theory of relativity. Whittaker's treatment placed a heavy emphasis on the work of Poincaré and Lorentz and dismissed Einstein's contribution as being of rather minor significance. Born, who himself wrote a book on the theory of relativity, was most unhappy with Whittaker's manuscript and sent him a long report in which he analyzed in detail the various contributions, indicating why he considered Einstein's contribution to be much more fundamental.



Members of Max Born's department at the time of his retirement (1953) from the Tait Chair of Natural Philosophy at the University of Edinburgh. Standing (from left to right)" E. Wolf, D. J. Hooton, A. Nisbet. Sitting: Mrs Chester (secretary), M. Born, R. Schlapp.

However, Born did not succeed in changing Whittaker's opinion. In September of 1953, around the time Whittaker's book was published, Born wrote to Einstein about this. Let me quote from Born's letter (Born, 1971, p.197): "Many people may now think (even if you do not) that I played a rather ugly role in this business. After all it is common knowledge that you and I do not see eye to eye over the question of determinism."

Einstein was not concerned. This is what he said in his reply to Born (Born, 1971, p.199): "Don't lose any sleep over your friend's book .... If he manages to convince others, that is their own affair. I myself have certainly found satisfaction in my efforts...." and then Einstein added, "After all, I do not need to read the thing."

Born retired that year, in 1953. The accompanying photograph shows Born with the members of his department at the time of his retirement.

8 Life in retirement

Soon afterward the Born's left Edinburgh and settled in Bad Pyrmont, a spa in West Germany, not far from Göttingen, where they built a small house. When they left Edinburgh our book was far from finished. We corresponded about it, and I visited Born in his new home several times. Born was hoping that he and Mrs. Born would be able to lead a more quiet life in Bad Pyrmont, but he told me on one of my visits that this proved difficult to achieve. For example, soon after they settled in Bad Pyrmont, Born was invited to address a meeting of a West German physical society. He declined the invitation, saying that he was too old to travel. He received a reply stating that in view of this the meeting would be moved to Bad Pyrmont!

In 1954, the year after his retirement, Born was awarded the Nobel Prize. He was, of course, delighted, but I am quite sure he felt, as many others did, that this great recognition had come somewhat late. The Nobel Prize was awarded to him for contributions that he made almost 30 years earlier. However, as his son Gustav later noted in a postscript to Born's memoirs (Born, 1978, p.296), it came at the right time to add weight to his main retirement occupation, which was to educate thinking people in Germany and elsewhere in the social, economic, and political consequences of science and also of the dangers of nuclear weapons and re-armament.

Max Born 1954

In 1957 I was a Visiting Scientist at the Courant Institute of New York University, still working on our book. One day I received a letter from Born asking me why the book was not yet finished. I replied that practically the whole manuscript was completed, except for a chapter on partial coherence on which I was still working. Born wrote back almost at once, saying something like, "Who apart from you is interested in partial coherence? Leave that chapter out and send the rest of the manuscript to the printers." Actually I completed that chapter shortly afterward and it was included in the book.

It so happened that within about two years after the publication of our book (in 1959) the laser was invented and optical physicists and engineers then became greatly interested in questions of coherence. Our book was the first that dealt in depth with this subject, and Born was then as pleased as I was that the chapter was included.

Our book was also one of the first textbooks containing an account of holography. Gabor was very happy about it. Later, when holography became popular and useful, he sent me a reprint of one of his papers with a charming dedication. As I approach the end of my reminiscences about Max Born, I would like to say that I hope my talk conveyed to you the warmth and the affection with which he remains in my memory, not only as a great scientist, but also as a kind and remarkable human being. My feelings about our collaboration are well described by exactly the same words that Born used when he spoke about his association with David Hilbert, quoted earlier, namely that my appointment with him was precious to me beyond description, because it enabled me to see and to talk to him every day.

9 Olivia

Hedwig Born and Max Born, with their daughter Irene Newton-John in Bad Pyrmont, 1957. (Credit: AIP Niels Bohr Library).

Before ending I would like to show you a few pictures taken in Bad Pyrmont during Born's retirement and also to mention one more episode. One shows Professor and Mrs. Born with one of their daughters, Irene. Some years ago I learned that Irene is the mother of a lady who has achieved fame comparable to that of Max Born himself, but in an entirely different field. I am speaking of the pop singer Olivia Newton-John. Shortly after I learned that Olivia Newton-John was Max Born's granddaughter, I was on a sabbatical leave at the University of Toronto. Olivia was scheduled to give a concert in Toronto while I was there. I wrote to her, told her I had collaborated with her grandfather in the writing of a book, and asked her whether we could meet. I received a charming reply in which she invited me to meet her after the concert. We met then and talked mainly about her grandparents. Before I left Olivia gave me two autographed photos of herself. Let me add that to some of my students I am known not so much as the co-author of *Principles of Optics* but rather as the person who knows Olivia Newton-John and who has a picture of her hanging in his office signed 'To Emil, Love, Olivia."

I cannot bring you the voice of Max Born, but I will end my presentation with one of the songs that made Olivia famous. (The lectures on which this article is based concluded with an excerpt from the song "If You Love Me Let Me Know.")

10 Acknowledgments

In preparing this article for publication I received assistance with obtaining some of the photographs, determining the approximate dates when they were taken and with checking some of the references. I am particularly obliged to G. V. R. Born (London University), R. M. Sillitto and S. D. Fletcher (University of Edinburgh), L. H. Caren (University of Rochester), and D. Dublin (American Institute of Physics) for their help.

References

Born, M.: 1971, *The Born-Einstein Letters*, Walker and Company, New York
Born, M.: 1978, *My Life*, Taylor and Rancis, London, and Charles Scribner's Sons, New York, p. 296
Infeld, L.: 1941, *Quest: The Evolution of a Scientist*, Doubleday, Doran & Co., New York
Reid, C.: 1970, *Hilbert*, Springer-Verlag, New York, Heidelberg, Berlin, p. 103

From left to right: Anthony E Siegmann (Stanford), Charles H. Townes (Nobel Prize 1964), Mrs. Wolf, Emil Wolf and Bernhard Braunecker during the opening session of the Max-Planck-Institute for the Physics of Light in Erlangen 2004.

Jost Bürgis genialer Artificium-Kunstweg entdeckt

Fritz Staudacher, Widnau

Der im Toggenburger Städtchen Lichtensteig geborene Uhrenmacher Jost Bürgi (1552–1632) hat 1584 nicht nur die erste Sekundenuhr der Welt gebaut, sondern er war auch einer der bedeutendsten Mathematiker des 16. Jahrhunderts. Dies nicht alleine schon wegen seiner Logarithmentafeln, sondern ebenfalls wegen seines Artificium-Kunstweges. Er wurde 1588 als Rätsel publiziert, aber erst jetzt nach 427 Jahren gelöst. In diesem Bürgi-Kunstweg ist auch die erste Differenzenrechnung enthalten. Als deren Erfinder hatte bis jetzt der britische Mathematiker Henry Briggs (1616) noch vor Isaac Newton gegolten.

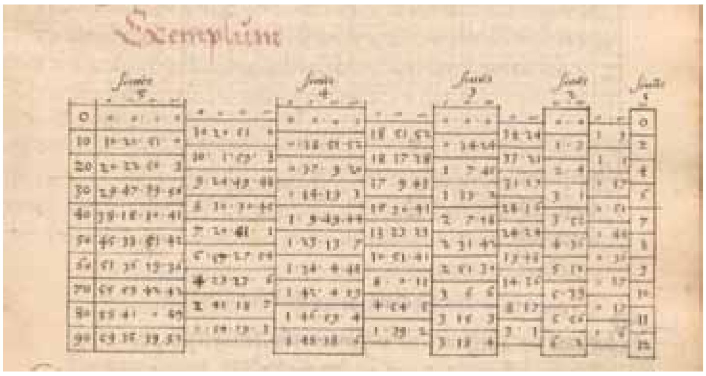
Entdeckt wurde Bürgis Lösung mit der weltweit ersten formalisierten Berechnung einer mathematischen Differenzenfolge erst kürzlich in einer 190-seitigen Handschrift, die Jost Bürgi 1592 dem Kaiser Rudolf II. in Prag übergeben hatte. Sie wird heute in der polnischen Universitätsbibliothek Wroclaw (Breslau) aufbewahrt. Zwei Seiten dieses *Fundamentum Astronomiae* bilden in tabellarischer Form den Rechenprozess ab, der als Bürgis ungelöstes *Artificium*-Kunstwegrätsel in die Mathematikgeschichte einging.

Bürgis Artificium-Rätsel offiziell 427 Jahre ungelöst

Jost Bürgis *Artificium* ist eine einzigartige Rechenmethode, um Sinustabellen zu erstellen, die in der Frühen Neuzeit immer wichtiger wurden. Benötigt wurden diese Tabellen für die Berechnungen der Sternpositionen – und je genauer sie waren, desto genauer wurden die Navigationskarten für die Kriegs-, Handels- und Expeditionsschiffe auf den Weltmeeren. Desto genauer auch konnte Bürgi-Freund Johannes Kepler – mit dem Bürgi acht Jahre am Prager Kaiserhof Rudolfs II. zusammenarbeitete – den elliptischen Bahnverlauf des Planeten Mars bestimmen. Erstmals veröffentlicht wurde Bürgis *Artificium* 1588, dies jedoch nur in Rätselform und mit punktiertem Tabellen-Schema von Nikolaus „Ursus" Reimers ohne Zustimmung des Erfinders. Trotz zahlreicher Versuche blieb dieses Rätsel 427 Jahre bis jetzt ungelöst. Selbst als sich 1973 zwei Mathematiker der renommierten Kepler-Kommission noch einmal intensiv mit dem Problem auseinandersetzten, kamen sie zum Schluss, dass es sich „um ein Interpolationsverfahren handle, das sich höherer Differenzen bedient", ohne das im Rätsel enthaltene Schema einer Tabelle weiter deuten zu können.

Forschungsautor Launert: „Ein doppelter Geniestreich!"

Der schleswig-holsteinische Mathematiker Dieter Launert gilt seit seiner Dissertation über Bürgi-Freund Nikolaus „Ursus" Reimers und dem 2009 für seine von der Bayerischen Akademie der Wissenschaften mit dem Akademiepreis ausgezeichnete Arbeit über die Reimersche Algebra als bester Kenner dieser wichtigen Phase. Er ist mit Menso Folkerts (München) und Andreas Thom (Dresden) Koautor des seit Mitte Oktober im arXiv.math.HO einsehbaren und zur Veröffentlichung in der *Acta Mathematica Historica* vorgesehenen Artikels *Jost Bürgi's Method for Calculating Sines* sowie auch Verfasser des Ende November gedruckt vorliegenden Forschungsberichtes über Bürgis Fundamentum *Astronomiae*. Launert sagt, mit dem in diesem Manuskript erstmals erläuterten *Artificium* sei dem damals am Fürstenhof von Hessen-Kassel als Hofuhrmacher angestellten 35-jährigen Jost Bürgi ein doppelter Geniestreich gelungen. Einmal durch die Erfindung einer algebraisch-arithmetischen Rechenmethode zur unkonventionellen Lösung einer eigentlich der Geometrie zuzurechnenden Aufgabenstellung: sie erlaubt es Bürgi, von einem gleichmässig unterteilten Viertelkreisbogen alle Sinusse einschliesslich Differenzen und der Differenzen von Differenzen sowie mit der daraus erstellten Sinustabelle astronomische sphärische Dreieckspositionen zu bestimmen. Bürgis zweiter Geniestreich besteht darin, durch eine didaktisch einmalige Methode den Grossteil des Rechenprozesses der Sinusteilung mittels dieser Tabelle auf einfache fortlaufende Additionen und wenige Werthalbierungen herunter zu brechen." Die Berechnung der Sinusse beginnt in dieser *Artificium*-Tabelle vollkommen unkonventionell rechts unten und zieht sich aufsummierend mäanderförmig über alle Spalten bis zu den Resultatzeilen in der ersten Kolonne, die anschliessend noch einer Anpassung durch Division unterzogen werden. Dieter Launert weist in seinem Forschungsbericht nach, dass bei fünf Stufen eine Genauigkeit erreicht wird, die im dekadischen System 6-7 Stellen entspricht, und bei sieben Stufen bereits 10–11 Stellen.



Jost Bürgis Artificium-Kunstweg (1586/88) aus seinem Fundamentum Astronomiae (1587/92). Zwei geniale Ideen in Form einer Tabelle mit automatisierter Generierung der Sinuswerte einschliesslich ihrer ersten und höheren Differenzen. Der Rechenprozess (hier von Bürgi im Hexagesimalsystem geschrieben) startet rechts unten und durchläuft mit kumulativer Summation alle Spalten mäanderförmig. Die fortlaufend entstehenden Sinuswerte bekommt man aus der ersten Kolonne als Verhältnisse zum letzten Wert $59/60 + 35/60^2 + 19/60^3 + 52/60^4$. Damit erzielt Jost Bürgi bei der hier abgebildeten fünfstufigen Variante gemäss Launert und Waldvogel eine Genauigkeit von 6–7 Dezimalstellen und bei Weiterführung zur siebenstufigen Sinustabelle von 10–11 Dezimalstellen. © The University Library in Wroclaw; Manuscript IV Q 38 a, fol. 36r.

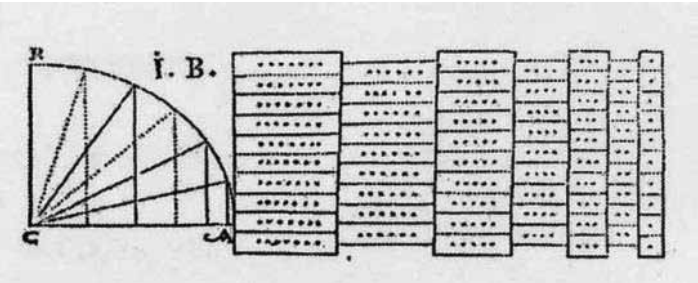
Methode von eleganter Schlichtheit und hoher Effizienz

Der emeritierte Mathematikprofessor Jörg Waldvogel war mit Bürgi-Biograph Fritz Staudacher der erste Experte der Schweiz, der über den Fund von Jost Bürgis *Artificium* unterrichtet worden war. Erst kurz zuvor hatte Jörg Waldvogel mit den modernen Methoden des Computerzeitalters die

Die Renaissance des Jost Bürgi

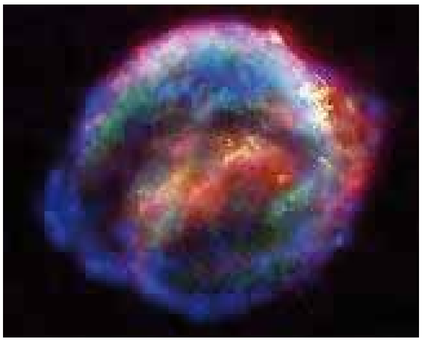
Noch immer ist dieses Schweizer Renaissancegenie Jost Bürgi kaum bekannt. Das könnte sich langsam ändern, erlebt er publizistisch doch gerade selbst eine Renaissance. Eine Trilogie nennt Dieter Launert die drei Werke, die in den beiden kommenden Monaten erscheinen – jedes für eine spezielle Zielgruppe.
Ende November soll die wissenschaftlich umfassende Studie Dieter Launerts „*Bürgis Kunstweg im Fundamentum Astronomiae. Entschlüsselung eines Rätsels*“ in der Reihe Nova Kepleriana des Verlages der Bayerischer Akademie der Wissenschaften vorliegen. Sie enthält die mathematische Analyse und die Geschichte dieses *Artificiums*.
Als zweites Werk legt Anfang Dezember der Verlag NZZ Libro die Biographie „*Jost Bürgi, Kepler und der Kaiser*“ von Fritz Staudacher in dritter erweiterter und überarbeiteter Auflage vor. Alleine 14 neue Zusatzseiten des gewichtigen und mit 270 historischen Bildern reichhaltig illustrierten Bandes widmet Staudacher Bürgis Kunstweg. Er geht auch Fragen nach, ob und wie es zum geheimen Transfer des Kunstweges nach England gekommen sein dürfte.
Die dritte Publikation „*Jost Bürgi's Aritmetische und Geometrische Progress Tabulen mit Kurzem Bericht*“ der amerikanischen Mathematik-Didaktikprofessorin Kathleen M. Clark ist das erste in englischer Sprache publizierte Werk Bürgis überhaupt. Es erscheint Anfang Januar im Wissenschaftsverlag Springer-Birkhäuser Basel und enthält auch die erste deutschsprachige Faksimileedition dieses Bürgischen Logarithmenwerkes.

mathematischen Charakteristiken der Bürgischen Logarithmen inklusive Fehlerresistenz sowie anwenderfreundlicher Konzeption und Ausführung untersucht und darüber in der Fachzeitschrift „Elemente der Mathematik“ berichtet. Jörg Waldvogel über seinen ersten Gedanken, als er Bürgis Kunstwegtabelle sah: „Von gleich elementarer Schlichtheit, Schnörkellosigkeit und Genialität ist auch dieses nach mehr als vierhundert Jahren jetzt ans Tageslicht gekommene *Artificium* Jost Bürgis mit einem beeindruckend einfachen Algorithmus. Er hatte gesehen, dass die zweite Differenz in einer Sinustabelle proportional zu den Sinussen selbst ist, und hatte dies genial genutzt und umgesetzt!“



Bürgis Artificium-Rätsel-Tabellenschema, veröffentlicht zusammen mit anderen Hinweisen 1588 von Nikolaus Reimers in dessen Fundamentum Astronomicum als Rätsel.

Jost Bürgi (1552–1632), 67-jährig. Erfinder der Logarithmen und des Artificium-Kunstweges (Differenzenrechnung). Erbauer der ersten Sekundenuhr und unübertroffener Himmelsgloben. Konstrukteur des ersten metallenen Sextanten, eines Triangulationsgerätes und des Proportional-Reduktionszirkels. Erfahrener astronomischer Beobachter und Mitersteller des ersten Sternkataloges der Frühen Neuzeit in Kassel vor Tycho Brahe. Je ein Vierteljahrhundert angestellt als fürstlicher Kammeruhrmacher in Kassel (1579–1604) und als Kaiserlicher Hofuhrmacher in Prag (1604–1631), davon acht Jahre mit Johannes Kepler am Kaiserhof Rudolfs II. auf dem Hradschin. (Porträtzeichnung und anschliessender Kupferstich von Aegidius Sadeler 1619 in Prag; erstmals veröffentlicht 1648).



Nach vier Jahrhunderten erfasste Reststrahlung von Keplers Stern, den Jost Bürgi 1604 in Prag mit seinem Freund Johannes Kepler im Fusse des Schlangenträgers beobachtete. Er ist die bisher letzte in unserer Milchstrasse explodierte Supernova. Ihre verbliebene Strahlung wurde von NASA/ESA/JHU im Juni 2000 im Infrarot-, Sichtbar- und Röntgenbereich erfasst und zu diesem Bild zusammengefügt.
Auch Bürgis Innovationen strahlen bis in unsere heutige Zeit. Wie wir heute wissen, hatte Jost Bürgi bereits damals seine grossen mathematischen Methoden des Artificium-Algorithmus und der Logarithmentafeln verfügbar. Jost Bürgis Instrumente zur Zeit- und Positionsbestimmung, seine Mathematikmethoden und seine eigenen astronomischen Beobachtungen im ersten Sternverzeichnis der Frühen Neuzeit (Grosser Hessischer Sternkatalog von 1587) sowie seine der Realität höchst angepassten uhrwerkgetriebenen Himmelsgloben prägten die Astronomie jener Zeit stärker als jeder andere mit Auswirkungen bis in unsere Zeit.

Joint EPS-APS Historic Site "Einstein House"

Bernhard Braunecker

Progress in Physics has many roots, which are spread all around the world. It is a great idea to identify and consequently distinguish those localities where most important contributions to Physics had their origin. One of those 'holy' places is the Einstein house in Kramgasse 49 in the heart of Switzerland's capital Bern, where the patent clerk Albert Einstein lived with his family in a flat in the second floor from 1903 to 1905.

The Einstein house now has been recognized by the European Physical Society EPS and the American Physical Society APS as a joint EPS-APS Historic Site. On September 14th 2015, a short celebration, unveiling a plaque in Einstein's former flat, took part in the presence of Christophe Rossel, EPS President, Samuel Aronson, APS President, Minh Quang Tran, SPS President, and Alexander Tschäppät, Mayor of Bern.

H.R. Ott, C. Rossel, M. Q. Tran, A. Tschäppät, S. Aronson (from left) unveiled the plaque.

The event was opened by Professor Hans Rudolph Ott, the chair of the Swiss Einstein-Society, who introduced Professor Norbert Straumann from the University of Zürich. He gave an exciting overview about those years and reported about the "revolutionary" and pioneering articles, which Einstein completed between March and June 1905, living there.

- "**On a heuristic point of view concerning the production and transformation of Light**" (17 March 1905). For this work about the Photoeffect he received the Nobel prize 1921.
- "**A new determination of molecular dimensions**" (30 April 1905) (Einstein's PhD Dissertation)
- "**On the movement of small particles suspended in stationary liquids required by the molecular–kinetic theory of heat**" (11 May 1905)
- "**On the electrodynamics of moving bodies**" (20 June 2015), the theory of special relativity,
- And followed by "**Does the inertia of a body depend upon its energy content?**" (27 September 1905), describing the equivalence of mass and energy.

Einstein announced the first four late in May 1905 to his friend Conrad Habicht: "*I promise you four papers in return. The first deals with radiation and the energy properties of light and is very revolutionary, as you will see if you send me your work first. The second paper is a determination of the true sizes of atoms… The third proves that bodies on the order of magnitudes of 1/1000 mm, suspended in liquids, must already perform an observable random motion that is produced by thermal motion. Such movement of suspended bodies has actually been observed by physiologists who call it Brownian molecular motion. The fourth paper is only a rough draft at this point, and is an electrodynamics of moving bodies which employs a modification of the theory of space and time.*"

Einstein and friends from 1905

All three presidents expressed the historical importance of this location where a young man who had to fully concentrate on his daily work as patent clerk, changed the world in his free time. And as N. Straumann pointed out: "*An annus mirabilis, as the one of Einstein in 1905, science had not seen since 1666, when Newton at an age of 24 developed calculus, an analysis of the light spectrum, and the laws of gravity.*"

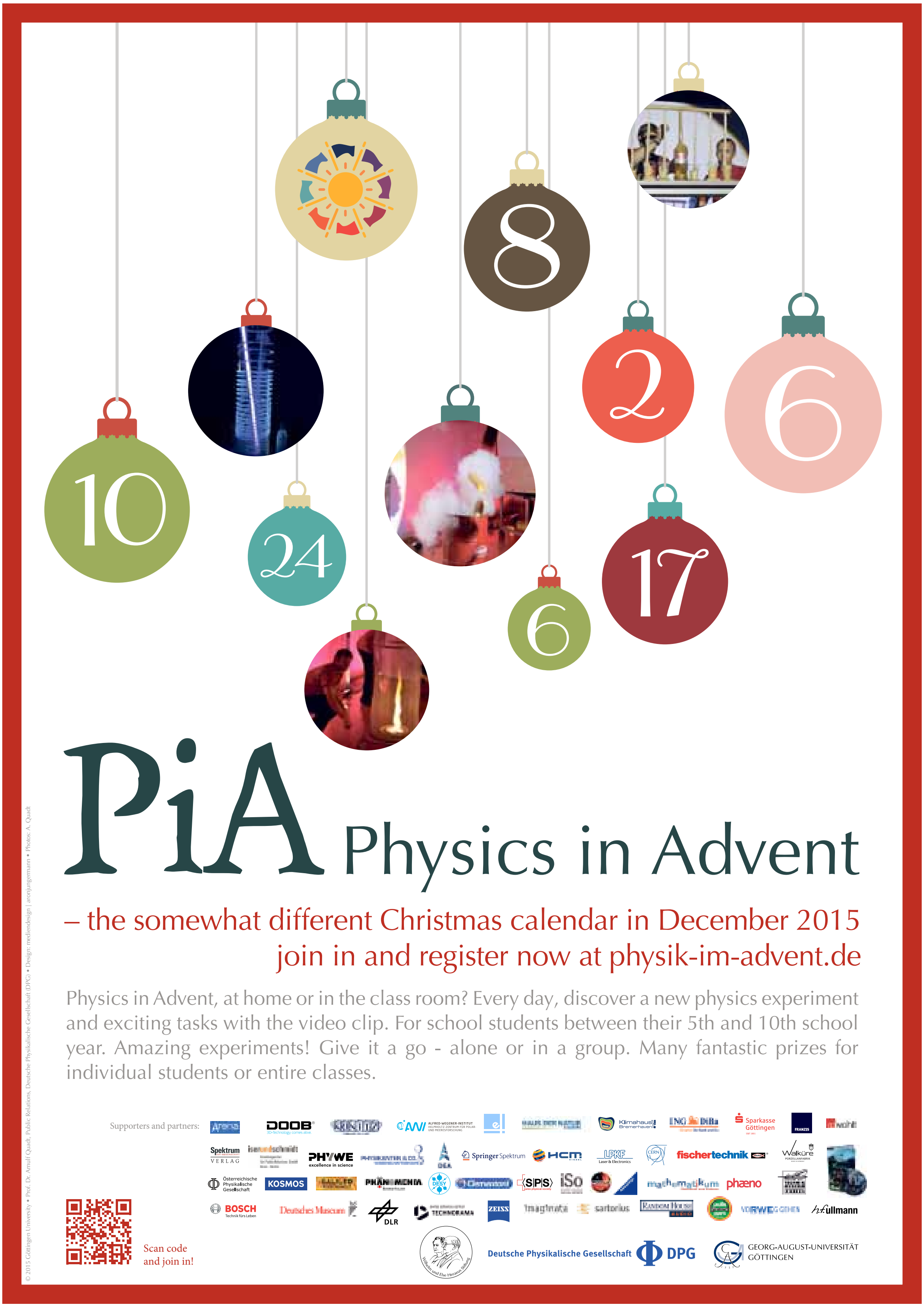
The mayor Alexander Tschäppät stressed the importance of the Einstein House for the city of Bern, even more important than the famous Bernese producer of chocolate! Hopefully he and the city succeed soon to buy the Einstein house from its current private owners.

We strongly recommend a visit of the flat on the second floor which has been restored in the style of that period, and the small, but impressive exhibit in the third floor, where Einstein's biography and his life's work are presented.

PiA - Physics in Advent

The Swiss Physical Society invites everyone who enjoys being a young scientist to register now at http://physik-im-advent.de. In this special physical advent calendar, 24 simple and yet ingenious experiments and physics puzzles invite to be tried out at home with your family and friends or just for yourself. You can answer the outcome of every experiment on the web page throughout the day before seeing the solution video the next day. The videos will be in German, with optional subtitles in French and English.

The Swiss Physical Society is sponsoring special prices for individual pupils and for whole school classes from Swiss schools, classes 5 to 10, which will be drawn among the best performing participants. "PiA - Physics in Advent" is free and young and old can participate; if you are a 5th to 10th grader, you may even win a prize.



Emmy Nöther Distinction for Anna Fontcuberta i Morral

The 2015 Emmy Nöther Distinction was awarded to **Prof. Anna Fontcuberta i Morral** of the Ecole Polytechnique Fédérale de Lausanne. The Emmy Nöther Distinction was established by the European Physical Society (EPS) to bring noteworthy women physicists to the wider attention of the scientific community, policy makers and the general public and to identify role models that will help to attract women to a career in physics. Prof. Fontcuberta received the Distinction on Friday 2^{nd} of October 2015 during a ceremony at the Rolex Center of the EPFL, in presence of Prof. Lucia di Ciaccio, Chair of the Equal Opportunities Committee of the EPS.

From left to right: Prof. Benoit Deveaud, President of the EPFL Research Commission, Prof. Lucia di Ciaccio, Chair of the Equal Opportunities Committee of the EPS and Prof. Anna Fontcuberta i Morral.

Prof. Fontcuberta has a prestigious scientific career. After a PhD at *Ecole Polytechnique, France*, she she worked on leave from the *Centre National de la Recherche Scientifique* (CNRS, France) as a visiting scientist at Caltec, the *California Institute of Technology* and at the "Walter Schottky Institut" of the *Technical University of Munich*. She joined the EPFL in 2008 as Assistant Professor Tenure Track and is Associate Professor since 2014. She is head of the Laboratory of Semiconductor Materials.

The SPS is proud to present a short interview of Prof. Fontcuberta, which was held in her laboratory a few days later.

Personal Questions

What would you suggest to a society like SPS to enhance the proportion of young female student in physics?
This is not a question with a simple answer, but I feel strongly about the importance that female students should be taken seriously from an early age, before starting secondary studies. The lack of women in physics comes from the prejudice and teachers seem to play a significant role. At EPFL, for example, we always remind people to take account that there are female and male students and their way of handling situations and/or answering could be different. On the other hand we should be fair with people and not to try to treat women differently. I think that we should be conscious of this and everybody could do something to enhance the proportion of young female student in physics.

In my personal case, I have always been interested in understanding matter. My father wanted me to become an engineer and my family always pushed me in this way. Instead I choose physics to understand everything from the root, which would help me later to work in the structure of matter. I was convinced that I should first study from the fundamentals to go further.

How did you approach the topic of nanostructures?
I like this field, because it offers the possibility to find new properties; this also opens many prospective, which is a lot of fun.

How important were later your international contacts & networks?
I think that contacts and networking are crucial for everybody. Female or male researchers should always discuss together to make science advance and go further.

Physics

Could you tell the readers of the "SPS Communications" more about the science you are performing?
My research activities are centred on the materials science and engineering of semiconductor nanostructures. With my team, we aim at making high-quality new physical objects using new combinations of materials. Then we study their properties. The final goal is to have novel and more functional structures for photovoltaics.

How important are the interactions with theory?
Yes, when we discover something unexpected, we rely on theoreticians to understand the properties. So the link with theory is of great importance.

Transfer to Industry

How would you transfer to industry ?
We make the samples ourselves by molecular beam epitaxy. If one would consider the industrialisation, I would first try the production of the samples by MOCVD, then transfer to a company.
To start production, we would first need an initial investment to go further in the labs because we only do mainly basic research. The way we work in our labs is not the best and cheapest way to fabricate new materials, but we could find less expensive ways of fabrication, but this would need investment if we wanted to do it at EPFL.

Economy

Is Switzerland well positioned here in research?
Switzerland is very strong in innovations and has many schemes or institution that helps link research with industry (e.g. CTI, CSEM) and I think that this is unique in the world and I like what they are doing and this is important for the country.

Kurzmitteilungen - Short Announcements

Die SATW in der Romandie

Die Schweizerische Akademie der Technischen Wissenschaften (SATW) ist das bedeutendste, unabhängige Schweizer Netzwerk im Bereich der Technikwissenschaften. Mit etwa 300 Einzelmitgliedern und 60 Mitgliedsgesellschaften gehören insgesamt rund 40‘000 Fachleute dazu. Davon leisten jedes Jahr gegen 500 Personen Beiträge in Projekten und Veranstaltungen, wobei die zahlreichen und vielseitigen Aktivitäten der Mitgliedsorganisationen nicht mitgezählt sind.
Der SATW ist es wichtig, das Technikverständnisses in der Gesellschaft und den Nachwuchs für die technischen Disziplinen zu fördern, aber auch die Zusammenarbeit von Hochschulen und Industrie. Die Erhaltung eines wettbewerbsfähigen Werkplatzes in der Schweiz ist dabei ein zentrales Anliegen.
In der Romandie ist die SATW im Bereich der Nachwuchsförderung bereits gut vertreten. So führt sie seit 2012 an den Westschweizer Gymnasien so genannte TecDays durch und publiziert das Jugendmagazin Technoscope auf Französisch. Nun sollen dank der Niederlassung weitere Aktivitäten zu den Schwerpunktthemen der SATW folgen, zum Beispiel zur Cyber Sicherheit oder zu Advanced Manufacturing.
Für die SATW ist neben den Beziehungen zu Politik, Industrie und Bildung auch die Nähe zur Wissenschaft wichtig. So sind unter den 300 Einzelmitgliedern viele aktive und ehemalige Professoren von Schweizer Universitäten und Fachhochschulen. Die SATW ist deshalb erfreut, neben ihrem Hauptsitz in Zürich auf dem Campus der EPFL einen Arbeitsplatz zu erhalten, und hat kürzlich mit der EPFL einen entsprechenden Vertrag unterzeichnet. Dieser tritt auf den 1. Januar 2016 in Kraft. Zurzeit läuft die Suche nach einer geeigneten Person, welche die Aktivitäten der SATW in der Romandie betreut.

www.satw.ch

La SATW en Suisse romande

L’Académie suisse des sciences techniques (SATW) est le principal réseau indépendant dans le domaine des sciences techniques en Suisse. Elle compte environ 300 membres individuels sélectionnés et 50 sociétés membres. Au sens large, le réseau de la SATW comprend plus de 40'000 personnes en Suisse. Chaque année, près de 500 personnes fournissent des contributions à des projets et à des événements. Les activités des organisations membres ne sont pas incluses.
Parmi les priorités de la SATW, on peut citer la promotion de la compréhension technique au sein de la société, la promotion de la relève dans les disciplines techniques ainsi que la promotion de la coopération entre les hautes écoles et l’industrie. Le maintien d’une place économique compétitive en Suisse est une question fondamentale.
En Suisse romande, la SATW est déjà bien représentée en matière de promotion de la relève. Ainsi, depuis 2012, elle organise les «TecDays» dans des gymnases de Suisse romande et publie en français le magazine pour les jeunes «Technoscope». D’autres activités portant sur les principales thématiques de la SATW doivent encore suivre, par exemple sur la cyber sécurité ou sur la fabrication avancée.
Outre les relations avec les milieux politiques, industriels et de la formation, la proximité avec les sciences est également essentielle pour la SATW. Parmi les 300 membres individuels, beaucoup sont des professeurs actifs ou anciens des universités suisses ou hautes écoles spécialisées. La SATW est donc ravie de bénéficier, en plus de son siège à Zurich, d’un lieu de travail sur le campus de l’EPFL, et a récemment signé un contrat en ce sens avec l’EPFL. Celui-ci entrera en vigueur le 1er janvier 2016. A l’heure actuelle, la SATW recherche une personne qui sera en mesure de gérer les activités de la SATW en Suisse romande.

www.satw.ch/index_FR

Zürcher Wissenschaftstage – 25 000 Besucher

Zürich strahlte am Wochenende des 4.-6. September mit seinen beiden Hochschulen als Wissenschaftsstandort: Die "**Scientifica**" verzeichnete bei ihrer vierten Ausgabe einen Besucherrekord: Rund 25‘000 Personen gewannen an 60 Ausstellungsständen und 40 Kurzvorlesungen Einblicke in das grosse Spektrum der Wissenschaft.
"Licht", ein grosses Thema der Physik. Entsprechend war das Departement Physik der ETH mit über 10% aller Ausstellungsstände und Vorträgen [1] präsent und bot dem zahlreichen Publikum einen breiten Einblick in Forschung und Studium. Den kleineren Besuchenden bot "Treffpunkt Science City" [2] zusätzlich einen Einblick in die Faszination der Physik anhand vielfältiger Experimente. Das grosse Interesse und die vielen spannenden Fragen des Publikums haben den Forschenden auch gezeigt, wie wertvoll der Dialog auch ausserhalb der Hochschulen ist.

"Es freut uns ausserordentlich, dass so viele Kinder, Jugendliche und Erwachsene die *Scientifica* besucht haben und sich von unserer Forschung faszinieren liessen. Alle Beteiligte haben viel geleistet, um die *Scientifica* zu einem einmaligen Erlebnis zu machen. Dafür, aber auch bei allen Besucherinnen und Besuchern, möchte ich mich im Namen der ETH und der Universität Zürich bedanken", erklärt Prof. Detlef Günther, Vizepräsident für Forschung und Wirtschaftsbeziehungen an der ETH Zürich.

[1] *https://news.phys.ethz.ch/2015/07/29/zurcher-wissenschaftstage-4-6-sep-2015/*
[2] *https://www.ethz.ch/de/news-und-veranstaltungen/veranstaltungen/treffpunkt.html*

Regina Moser, ETH Zürich, Departement Physik, Betriebe, Visuelle Kommunikation/Outreach

International Year of Light at the EPFL

The schools' day at EPFL

On June 2nd 2000 children aged from 10 to 13 and their teachers visited EPFL and could run experiments and visit the labs during the whole day. This was a fantastic occasion to communicate about the International Year of Light. Several workshops, conferences and demonstrations were organized on the light theme.
http://journeedesclasses.epfl.ch/programme2015

Shedding the Light on the Light

On the occasion of the International Year of Light and Light-based Technologies 2015, on November 7th, the EPFL proposes a special day dedicated to light for 7 to 13 years old youngsters and the general public.
During the whole day youngsters will have the opportunity to attend physics and chemistry hands on workshops. They will make a solar lamp, recompose the white light from colours, or produce light from chemical reactions for example. They will also attend a conference on the Northern Lights and they day will be closed by an official ceremony where all participants will get a certificate.
On November 7th 2015 afternoon in parallel to the workshops for youngsters, a series of short presentations aimed at the general public is organized where experts will talk about light. Different aspects of light in relation with science, art, theology, health and technology will be described in a language suitable for a diverse audience.
For more information: *http://sps.epfl.ch/cms/site/sps/lang/fr/AnneeLumiere*

EPFL to host International Year of Light celebration

On December 5th 2015, EPFL will host an event to promote the progress and promise of light technologies and research. The program will mark the closing Ceremony of the International Year of Light in Switzerland and will feature the latest in photonics as well as leading scientists to promote improved public understanding of the central role of light in the modern world.

This celebration will bring together bright minds from Google X, Bell Labs, Intel, Philips, UNESCO or IBM Research among other, as well as an ESA astronaut and a Nobel Laureate, to foster learning, inspiration and wonder. A laser show and performances will punctuate the ceremony. Don't miss the surprise visible from space that day!

More info and tickets: *www.iyl2015.ch*

The International Year of Light and Light-Based Technologies (IYL 2015; www.light2015.org) is a global initiative adopted by the United Nations to raise awareness of how optical technologies promote sustainable development and provide solutions to worldwide challenges in energy, education, agriculture, communications and health.

INTERNATIONAL YEAR OF LIGHT 2015

Maurice Campagna zum Präsidenten der Akademien der Wissenschaften Schweiz gewählt; Thierry Courvoisier wird nächster EASAC Präsident

Maurice Campagna ist von der Delegiertenversammlung zum neuen Präsidenten der Akademien der Wissenschaften Schweiz gewählt worden. Er übernimmt ab dem 1. Januar 2016 das Amt von Thierry Courvoisier.

Maurice Campagna forschte nach einem Doktorat in Physik an der ETH Zürich zunächst in Cambridge, UK, und an den Bell Laboratories, Murray Hill, USA. 1977 wurde er an der Universität zu Köln zum Ordinarius für Physik berufen und wurde zum Direktor im Forschungszentrum Jülich ernannt. Nach der Berufung als Ordinarius für Physik an die ETH Zürich im Jahre 1986 wurde er 1988 Direktor für Forschung und Entwicklung bei der ABB. Seit 2003 ist er Geschäftsführer der Enterprise Consulting (Technologie und Mediation) in Ennetbaden/Aarau und Lugano.

Maurice Campagna war jahrelang Mitglied des Schweizerischen Wissenschafts- und Technologierates und ist seit 1989 Mitglied der Kommission Bildung & Forschung von Economiesuisse. 1983 wurde er zum Fellow der American Physical Society und 1998 zum Einzelmitglied der Schweizerischen Akademie der Technischen Wissenschaften SATW ernannt.

Maurice Campagna wird mit seiner breit abgestützten Erfahrung sowohl in akademischen wie auch in unternehmerischen Belangen eine verbesserte und fachübergreifende Zusammenarbeit der Akademien der Wissenschaften Schweiz erzielen, besonders mit Blick auf die aktuellen Perspektiven gesellschaftlichen und geopolitischen Umbruchs. Er ist für vier Jahre gewählt und übernimmt das Amt von Thierry Courvoisier, Professor für Astrophysik an der Universität Genf, der die Akademien von Anfang 2013 bis Ende 2015 präsidierte.

Thierry Courvoisier, zurzeit auch Vizepräsident des European Academies Science Advisory Council (EASAC), wird der nächste Präsident von EASAC für die Jahre 2017 bis 2019. Er wird Jos van der Meer ablösen, dessen Amtszeit als EASAC-Präsident im Dezember 2016 endet.

Aus den Medienmitteilungen der Akademien der Wissenschaften Schweiz

Ausschreibung der SPG Preise für 2016
Annonce des prix de la SSP pour 2016

Auch im Jahr 2016 sollen wieder SPG Preise, die mit je CHF 5000.- dotiert sind, vergeben werden.

En 2016, la SSP attribuera à nouveau des prix de CHF 5000.- chacun, à savoir:

- SPG Preis gestiftet vom Forschungszentrum ABB Schweiz AG für eine hervorragende Forschungsarbeit auf allen Gebieten der Physik
- Le prix SSP offert par le centre de recherche ABB Schweiz AG pour un travail de recherche d'une qualité exceptionnelle dans tout domaine de la physique

- SPG Preis gestiftet von der Firma IBM für eine hervorragende Forschungsarbeit auf dem Gebiet der Kondensierten Materie
- Le prix SSP offert par l'entreprise IBM pour un travail de recherche d'une qualité exceptionnelle en physique de la matière condensée

- SPG Preis gestiftet von der Firma OC Oerlikon für eine hervorragende Forschungsarbeit auf dem Gebiet der Angewandten Physik
- Le prix SSP offert par l'entreprise OC Oerlikon pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique appliquée

- SPG Preis gestiftet vom METAS für eine hervorragende Forschungsarbeit mit Bezug zur Metrologie
- Le prix SSP offert par le METAS pour un travail de recherche d'une qualité exceptionnelle faisant référence au domaine de la métrologie

- SPG Preis gestiftet von der Firma COMSOL für eine hervorragende Forschungsarbeit auf dem Gebiet der computergestützten Physik
- Le prix SSP offert par l'entreprise COMSOL pour un travail de recherche d'une qualité exceptionnelle dans le domaine de la physique numérique

Die SPG möchte mit diesen Preisen junge PhysikerInnen für hervorragende wissenschaftliche Arbeiten auszeichnen. Die eingereichten Arbeiten müssen entweder in der Schweiz oder von SchweizerInnen im Ausland ausgeführt worden sein. Die Beurteilung der Arbeiten erfolgt auf Grund ihrer Bedeutung, Qualität und Originalität.
Der Antrag für die Prämierung einer Arbeit muss schriftlich begründet werden. Die Arbeit muss in einer renommierten Zeitschrift publiziert oder zur Publikation angenommen sein. Wenn mehrere Publikationen eingereicht werden, um die Leistungen des Kandidaten umfassender darzustellen, muss genau gesagt werden, welche Publikation für die Preisvergabe in Betracht gezogen werden soll.

Der Antrag muss die folgenden Unterlagen enthalten:
Begleitbrief mit Begründung, Lebenslauf des Kandidaten mit Publikationsliste, die zu prämierende Arbeit und ein Gutachten.

Diese Unterlagen werden elektronisch im "pdf"-Format direkt an das Preiskomitee eingereicht (große Dateien bitte komprimieren (zip)):

La SSP aimerait saluer l'excellence d'un travail scientifique effectué par de jeunes physiciens ou physiciennes. Les travaux soumis à candidature doivent avoir été effectués en Suisse ou par des Suisses à l'étranger. L'évaluation portera sur l'originalité, l'importance et la qualité des travaux.
La candidature soumise à nomination doit être justifiée par écrit. Le travail doit avoir été publié dans une revue renommée ou être accepté pour publication. Si plusieurs publications sont présentées, dans le but de mieux décrire la performance du candidat, il faut préciser laquelle est à prendre en considération pour l'attribution d'un prix.

Le dossier de candidature doit comporter les documents suivants:
une lettre de motivation, le curriculum vitae des auteurs, une liste de publications, le travail proposé et une lettre de recommandation.

Ces documents seront envoyés électroniquement en format "pdf" directement au comité de prix (svp. comprimez des fichiers très grands (zip):

awards@sps.ch

Einsendeschluss: 29. Februar 2016

Délai: 29 février 2016

Die Preise werden an der Jahrestagung 2016 in Lugano überreicht. Das Preisreglement befindet sich auf den Webseiten der SPG: *www.sps.ch*

Les prix seront attribués à la réunion annuelle qui se tiendra en 2016 à Lugano. Le règlement des prix se trouve sur les pages Web de la SSP: *www.sps.ch*

MFLI
UHF