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Revidiertes Verhältnis zwischen Johannes Kepler und Jost Bürgi. August von Kreling (1819-1876) schuf dieses Bronzerelief für das 1870 in Weil der Stadt eingeweihte Kepler-Denkmal mit dem stehenden Kaiserlichen Mathematiker und dem knienden Kaiserlichen Kammeruhrmacher, die von 1603 bis 1612 in Prag eng zusammenarbeiteten. (Foto: Wolfgang Schütz).

Johannes Kepler appears twice in this issue: as person after whom the university in Linz was named, where our joint SPS/ÖPG meeting took place (p. 5), and as scientific partner of Jost Bürgi, see our book review on page 33.

The Austrian and Swiss award winners after the joint prize ceremony in Linz, together wit the SPS and ÖPG presidents and the president of the SPS award committee.

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The winners of the SPS Awards 2013

The SPS Award committee, presided by Prof. Louis Schlapbach, had the great pleasure to select the SPS award winners 2013 from many submitted papers of excellent scientific quality.
The winners presented their work at the joint annual meeting in Linz. Please find in the following the laudationes written by L. Schlapbach, and the summaries written by the authors.

SPS Award in General Physics, sponsored by ABB

Titus Neupert is awarded with the SPS 2013 Prize in General Physics for his pioneering PhD work, especially for his theoretical discovery of "Fractional quantum Hall states at zero magnetic field".

The integer and fractional quantum Hall effects were experimentally detected in 1981 and 1982, respectively, at cryogenic temperatures. The discovery of graphene in 2005 established that the integer quantum Hall effect could be achieved at room temperature. Theorists predicted that the integer quantum Hall effect was one out of many examples of a larger family of semiconducting states supporting quantized susceptibilities in materials called topological band insulators. Titus Neupert gave the first quantitative answer to the question whether strong interactions could drive a fractional topological insulator in very much the same way as interactions drive a fractional quantum Hall insulator. One of the most remarkable prediction made by the award winner is that, by taking advantage of materials with strong spin-orbit coupling, it might become possible to achieve a fractional quantum Hall effect that is robust at room temperature and this without the use of any laboratory magnetic field.

Fractional quantum Hall states at zero magnetic field

A central theme of condensed matter physics is to classify and understand phases of matter. The Landau theory of symmetry breaking has been the long-standing paradigm for this classification: Two phases are distinct if they have different symmetries.
In recent years, the study of topological phases showed that a second paradigm must be considered on equal footing: Two phases are distinct if they have different topological character, even if they share the same symmetries. Topological properties cannot be changed smoothly, thus endowing a topological state with a natural universality and protection against perturbations.
Topological phases are understood and classified in the limit of small electron–electron interactions. The opposite limit, in contrast, is at the frontier of current research. Strong electron–electron interactions can be responsible for the emergence of correlated topological states with excitations that have a fraction of the electron's charge, so-called fractional topological insulators (FTIs). The first example of an FTI that is well studied both experimentally and theoretically is the fractional quantum Hall effect of electrons in partially filled Landau levels. Recently, we discovered another type of FTIs, the fractional Chern insulator [1]. These states arise in lattice models in two spatial dimensions, if a nearly dispersionless band with a nonzero Chern number is partially filled with repulsively interacting electrons. Fractional Chern insulators share many universal and topological properties with the fractional quantum Hall effect in Landau levels, where the role of the strong magnetic field is replaced by time-reversal symmetry breaking electronic hopping integrals on the lattice. Comparing and contrasting the fractional Chern insulators with the fractional quantum Hall effect allows us to better understand what are the core ingredients for a fractional topological state to emerge.
In a combination of numerical and analytical work, we have studied several aspects of FTIs in two spatial dimensions. For example, we found that if a topological insulator, as is realized in HgTe quantum wells, has a sufficiently small bandwidth, repulsive electron–electron interactions can favor a spontaneous breaking of time-reversal symmetry along with the formation of an anomalous quantum Hall effect or a fractional Chern insulator state [2].

[1] T. Neupert, L. Santos, C. Chamon, and C. Mudry, Phys. Rev. Lett. 106, 236804 (2011).
[2] T. Neupert, L. Santos, S. Ryu, C. Chamon, and C. Mudry, Phys. Rev. B 84, 165107 (2011).

SPS Award in Applied Physics, sponsored by OC Oerlikon

Iris Crassee is awarded with the SPS 2013 Prize in Applied Physics for her excellent PhD work on magneto-optical properties of graphene and the discovery of giant Faraday rotation in the terahertz range in single and multilayer graphene epitaxially grown on silicon carbide. She pioneered the application of the infrared Hall spectroscopy, where both transmission and Faraday rotation are measured in a broad frequency range, to graphene, which allowed her to distinguish Landau-level transitions that stem from different graphene layers.

Giant Faraday rotation and magneto-plasmonic effects in graphene

We explored the complex structure of the Landau levels and cyclotron resonances in graphene epitaxially grown on silicon carbide. Epitaxial graphene is of particular practical importance because of a possibility for scalable growth. However, its properties are rather complicated because of a strong coupling of the carbon layers to the substrate, their unusual stacking and variation of doping across the layers. We were the first to apply the technique of the infrared Hall effect in monolayer and multilayer graphene, where both transmission and the Faraday rotation are measured. This allowed us to distinguish and classify spectroscopically various Landau-level transitions that stem from different graphene layers, including the buried ones, which are not accessible by other techniques. In particular, a multicomponent cyclotron resonance structure was observed in multilayer graphene grown on the C-face of silicon carbide.
In our study of doped monolayer graphene on Si-face of SiC, we discovered a giant Faraday rotation in the terahertz range that originates from the cyclotron resonance of free carriers [1]. The unprecedented value of the rotation angles (about 6 degrees at 7 T) by the thinnest material in condensed matter physics, contradicts common sense, since the Faraday effect is known to be proportional to the thickness. Nevertheless, we explained our observation by the extremely small mass of Dirac fermions and their high mobility, and numerically reproduced the experimental curves. In a follow-up publication [2], we found that due to the presence of substrate terraces, a strong terahertz plasmonic peak appears in epitaxial graphene. Furthermore, we found that the plasmon peak splits in magnetic field into bulk and edge magnetoplasmon branches, similar to the ones observed in some classical experiments on GaAs based 2D electron gases. This was actually the first observation of magnetoplasmons in graphene. Importantly, the plasmonic effects found by us modify dramatically the wavelengths dependence of the Faraday rotation. All these results are of a high practical importance as they suggest that graphene can be used in ultrathin and ultrafast switchable magneto-optical devices.

[1] I. Crassee, J. Levallois, A. L. Walter, M. Ostler, A. Bostwick, E. Rotenberg, Th. Seyller, D. van der Marel, and A. B. Kuzmenko, Giant Faraday rotation in single- and multilayer graphene, Nature Physics 7, 48–51, 2011.
[2] I. Crassee, M. Orlita, M. Potemski, A. L. Walter, M. Ostler, Th. Seyller, I. Gaponenko, J. Chen, and A. B. Kuzmenko, Intrinsic Terahertz Plasmons and Magnetoplasmons in Large Scale Monolayer Graphene, Nano Letters 12, 2470-2474, 2012.

SPS Award in Condensed Matter Physics, sponsored by IBM

Jelena Klinovaja is awarded with the SPS 2013 Prize in Condensed Matter Physics for her excellent theoretical work on hybrid superconducting-semiconducting nano structures in the presence of Rashba spin-orbit interaction as well as helical magnetic fields. Their interplay leads to a competition of phases with two topological gaps closing and reopening, resulting in unexpected reentrance behavior. Besides the topological phase with localized Majorana fermions (MFs) she found novel phases characterized by fractionally charged fermion (FF) bound states of Jackiw-Rebbi type. These most original pieces of work open up graphene-based materials to spin physics and in particular to Majorana fermions with non-abelian statistics, predicted to be useful for topological quantum computing.

SPS President Andreas Schopper together with Jelena Klinovaja and Frank Kassubek, member of the award committee.

Exotic Bound States in Low Dimensions

In a recent theoretical study, we found a new mechanism for generating Majorana bound states in nanowires with proximity gap that is based on spatially rotating magnetic fields, being present in addition to Rashba spin orbit interaction [1]. The topological phases can be completely characterized by a new method to find explicit solutions for Majorana fermions and other exotic fermion bound states of Jackiw-Rebbi type carrying fractional charge e/2. Due to their non-Abelian statistics such states can be used for braiding and are of potential use in topological quantum computing. More specifically, we analyzed hybrid superconducting-semiconducting nanowires in the presence of Rashba spin-orbit interaction as well as helical magnetic fields and showed that the interplay between them leads to a competition of phases with two topological gaps closing and reopening, resulting in unexpected reentrance behavior. Besides the topological phase with localized Majorana fermions (MFs) there are novel phases characterized by fractionally charged fermion (FF) bound states of Jackiw-Rebbi type. The system can be fully gapped by the magnetic fields alone, giving rise to FFs that transmute into MFs upon turning on superconductivity. Explicit analytical solutions for MF and FF bound states which allowed us to determine the phase diagram numerically by determining the corresponding Wronskian null space. Electron-electron interactions leave the bound states intact and even enhance the required Zeeman gaps opened by the fields.

In a follow up work on graphene, where some of the physics discovered in the first work might be implemented experimentally, we found an unusally large spin orbit effect in graphene nanoribbons (with armchair edges) produced by nanomagnets [2]. As a consequence, helical modes exist in armchair nanoribbons that exhibit nearly perfect spin polarization and are robust against boundary defects. This result paves the way for realizing spin-filter devices in graphene nanoribbons in the temperature regime of a few kelvins. If a nanoribbon in the helical regime is in proximity contact to an s-wave superconductor, the nanoribbon can be tuned into a topological phase that sustains Majorana fermions.

[1] Jelena Klinovaja, Peter Stano, and Daniel Loss, "Transition from fractional to Majorana fermions in Rashba nanowires", Phys. Rev. Lett. 109, 236801 (2012).
[2] Jelena Klinovaja and Daniel Loss, "Giant spin orbit interaction due to rotating magnetic fields in graphene nanoribbons", Phys. Rev. X 3, 011008 (2013).

Review of the Joint Annual Meeting in Linz

This year's Annual Meeting took place in Linz on 3-6 September 2013 and was jointly organized by the Swiss and Austrian Physics-, Astronomy and Astrophysics- Societies (SPS, ÖPG, SSAA, ÖGAA). The collaboration with the Austrian colleagues was very fruitful and all societies contributed to the excellent atmosphere of the meeting. The high quality of the scientific contributions was also reflected by the very well attended, comprehensive plenary sessions that covered a large variety of physics topics.

Despite the fact that Linz is somewhat remote and was difficult to reach for our Swiss colleagues, a fair fraction of the participants came from Switzerland. The high number of attendees (more than 550) shows again that this way of cooperating between the Swiss and Austrian communities is very effective and makes us already look forward to the next joint meeting in Vienna, in 2015.

A few highlights are worth mentioning:

The program listed two public lectures. The conference opening lecture on Tuesday evening was the first one, given by Mildred Dresselhaus (see further below). The second public lecture on Wednesday evening was held by the Nobel Prize laureate of 2012, Serge Haroche, Ecole Normale Supérieure (ENS) and Collège de France, Paris. In his talk entitled "Manipulation of single quantum systems", he showed experiments at the frontier of physics and information sciences, exploring the transition between the microscopic world ruled by the quantum laws and our macroscopic environment that appears "classical". The aim is to set-up experiments such that photons are detected in a non-destructive manner, by juggling with photons trapped between superconducting mirrors. The "Laboratoire Kastler Brossel" (a research unit depending on CNRS, ENS and Univ. P. et M. Curie) gave already birth to three Nobel prizes! A recipe? Haroche says that research is particularly successful when several conditions are met: no time pressure, confidence, and free research that is not governed by the laws of the market. To cite Niels Bohr: "It is hard to make predictions, in particular about the future".

Nine well-attended plenary talks covered a wide range of topics:

Richard Berndt, University Kiel, showed us in "Plasmons forces and currents in atomic and molecular contacts", how to play with a C_{60}-ball on top of a STM (Scanning Tunnelling

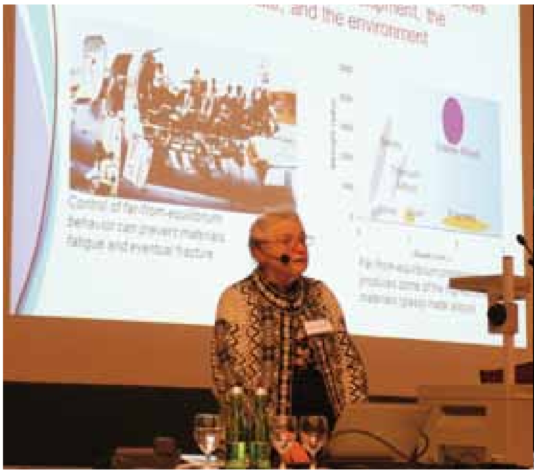
Microscope) tip, yielding spatial sensitivity in the range of ten picometres and addressing the role of molecular structure and bonding as well as quantum noise properties.

Peter Zoller, University of Innsbruck, showed in "Quantum simulation with atoms, ions and molecules" how the condensed matter and atomic physics communities have recently mutually benefited from synergies emerging from the quantum simulation of strongly correlated systems using atomic setups. With a point of humour he conveyed in the frame of symmetry breaking that "frustration makes life and physics interesting".

Rainer Blatt, also from Innsbruck, explored in "The quantum way of doing computations" how to increase computer power as, following Moore's law, we are soon to reach the material size limits due to the ever smaller size of electronic components thus entering in the quantum realm.

Jan Lacki, University of Geneva, in his talk "100 year Bohr's atomic model: it's birth and importance in the rise of QM", showed the multiple ways subjects expand and concepts develop. Among the people that made QM real: Bohr's model is the first application of quanta to the mechanics of individual systems, an approach opposite to Planck and Einstein who started from a macroscopic level to explain the energetic properties of radiation and mater to reach QM.

Lisa Kaltenegger, MPI Heidelberg, held a brilliant talk on "Exoplanets and their atmosphere". Atmosphere simulations – with 360 chemical reactions and 70 elements or molecules - illustrate the interplay between rocks and atmosphere contributing to a geochemical equilibrium and



Mildred Dresselhaus and Serge Haroche gave the two public lectures on Tuesday and Wednesday, respectively.

A humorous slide from Haroche's talk.

stabilizing the climate, like the carbonate-silicate cycle. Completing the observation of the spectral fingerprints of some 3500 exoplanets inside a 70 light-years range - 940 have been found so far - will allow a fruitful comparison with atmosphere evolution simulations, with a special curiosity for planets in the habitable zone ! This talk was in fact an ideal introduction to the issue of Earth climate addressed in the talk by Douglas Cripe (see further below).

Primoz Ziherl from University of Ljubljana showed masterly in "Theoretical insights into structure of animal tissues" how to put the growth of tissues in equations describing the mechanical interactions between their discrete components, and further how to evolve a shape from morula to blastula and to the large variety of shapes of living organisms.

In the joint award ceremony on Wednesday, three SPS awards (see p. 3) and five ÖPG awards together with several prizes for students and pupils were handed-over. Furthermore, for the second time EPL sponsored three prizes for the best posters, awarded to the winners in a short ceremony on Friday.

The winners of the Best Poster Awards: Reinhold Wartbichler, Uni Leoben, Laurin Ostermann, Uni Innsbruck, Cezarina Cela Mardare, Uni Linz. In the background: Emma Watkins, EPL representative.

It is remarkable that although the ÖPG does not have a dedicated Theory section, a session on this topic organised by the SPS together with J. Yngvason (Uni Vienna) was nevertheless very well attended, thanks to the high quality of the talks.

A session on "Biophysics, Medical Physics and Soft Matter" took also place in Linz, like a preliminary exercise before a new section on that theme would be formally created in 2014.

The traditional conference dinner took place in the "Pöstlingberg-Schlössl" with a nice view over the illuminated city of Linz. About 100 persons participated.

The following texts summarize some more aspects and sessions of the conference.

Nachbericht aus Sicht der Veranstalter

Die inzwischen alle zwei Jahre gemeinsam abgehaltene Jahrestagung von ÖPG, SPG, ÖGAA und SSAA wurde in der ersten Septemberwoche 2013 auf dem Campus der Johannes Kepler Universität (JKU) in Linz abgehalten. Als lokaler Veranstalter fungierte der Fachbereich Physik in Linz unter Federführung der Abteilung für Halbleiterphysik. Die Räumlichkeiten der JKU sind für Tagungen mit bis zu etwa 600 Teilnehmern relativ gut geeignet: So können bis zu 15 Parallelsitzungen, Postersitzungen mit bis zu 150 Postern, Plenarvorträge mit bis zu 450 Zuhörern und eine mittelgroße Firmenausstellung in einem einzigen Gebäude, dem Keplergebäude, abgehalten werden. Zudem kann das Catering vor Ort durch die Mensa gut abgedeckt werden. Für die Jahrestagung wurden diese Infrastruktureinrichtungen nahezu vollständig genutzt.

Die Programmerstellung und die Auswahl der Plenarsprecher erfolgte in bewährter Weise durch die Fachausschüsse bzw. Sektionen der Trägergesellschaften, denen es aus unserer Sicht gelungen ist, ein außerordentlich attraktives Programm aus nahezu allen Teilbereichen der Physik zu organisieren. Hier gilt unser besonderer Dank den Vorsitzenden der Fachausschüsse bzw. Sektionen für ihre hervorragende Arbeit. Der Programmbeitrag der lokalen Organisatoren hat sich auf den Vorschlag der beiden Public Lectures und auf die Organisation von drei Sondersitzungen beschränkt. Bei den Public Lectures ist es gelungen, Serge Haroche vom Collège de France als Sprecher zu gewinnen. Er hat vor etwa 400 Zuhörern einen exzellenten Überblick über seine Experimente zur Wechselwirkung von Lichtquanten mit Atomen gegeben, die 2012 mit einem Physik-Nobelpreis ausgezeichnet wurden. Zum anderen konnten wir Mildred

The plenary speakers: 1) Richard Berndt, Uni Kiel, 2) Peter Zoller, Uni Innsbruck, 3) Rainer Blatt, Uni Innsbruck, 4) Jan Lacki, Uni Genève,

The Pöstlingberg-Schlössl, a nice restaurant on the heights of Linz.

The presidents of the two societies, Andreas Schopper (SPS) and Wolfgang E. Ernst (ÖPG), after a very good dinner.

Dresselhaus vom MIT für den Eröffnungsvortrag der Tagung gewinnen. Die ehemalige Beraterin des US-Präsidenten Clinton hat mit ihrem Vortrag *Using nanostructures toward Achieving Energy Sustainability* eine Brücke geschlagen vom traditionellen *Energietag* der Fachausschüsse Energie und Industrie der ÖPG zum allgemeinen Programm der Tagung, in dem Nanostrukturen in mehreren Fachsitzungen eine wichtige Rolle gespielt haben. Die drei von uns zusätzlichen eingebrachten Fachsitzungen waren zum einen den Energiethemen *Thermoelectrics* und *Photovoltaics* gewidmet, die in Linz wichtige Schwerpunktthemen sind. Zum anderen wurde das Jahressymposium des internationalen Spezialforschungsbereichs *Infrared Optical Nanostructures* heuer unter dem gleichnamigen Titel als Fachsitzung in die Jahrestagung eingegliedert.

Zur Ergänzung des Programms, nicht zuletzt aber auch als wesentlicher Beitrag zur Finanzierung der Tagung, wurde eine Firmenausstellung mit 27 Ausstellern organisiert. Insbesondere die breite Abdeckung des Themenbereichs Vakuum, aber auch die Anwesenheit zahlreicher Aussteller aus dem Bereich Meßtechnik und Anlagenbau wurde von den experimentell orientierten Tagungsteilnehmern überaus positiv aufgenommen.

Mehr als 550 Personen haben an der Tagung mit insgesamt 400 Beiträgen teilgenommen. Davon wurden 116 als Posterbeiträge in drei Sitzungen abgehandelt. Neben den beiden Public Lectures gab es neun vielbeachtete Plenarvorträge sowie über 50 Invited Talks in den Fachsitzungen.

Die Tagung wurde unterstützt vom Land Oberösterreich, der Stadt Linz und der Johannes Kepler Universität. An der lokalen Organisation haben zahlreiche Personen aus dem Fachbereich Physik und insbesondere aus der Abteilung für Halbleiterphysik mitgewirkt. Hervorgehoben seien in diesem Zusammenhang Frau Mag. S. Schwind und Herr Ing. S. Bräuer, die in hohem Maße zum Gelingen der Tagung beigetragen haben. Unser besonderer Dank gilt Herrn S. Albietz von der SPG, der mit außerordentlichem Arbeitseinsatz die Programmkoordination und das Erstellen des Tagungsbandes übernommen hat und mit zwei Schweizer Kolleginnen vor Ort im Tagungsbüro tatkräftig mitgearbeitet hat. Unser Dank gilt auch dem Geschäftsführer der ÖPG, Herrn Prof. Dr. K. Riedling, der uns in allen Fragestellungen unterstützt hat. Nicht zuletzt bedanken wir uns bei den Präsidenten und Vorstandsmitgliedern der Trägergesellschaften für ihre Unterstützung.

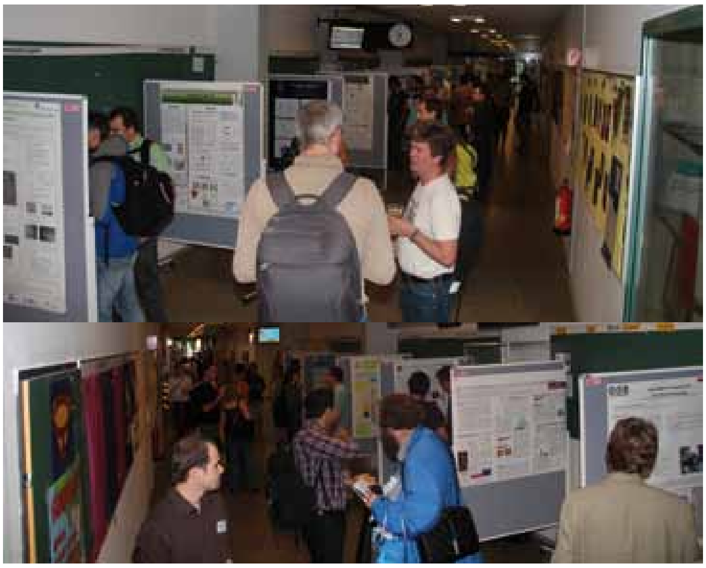
Armando Rastelli und Friedrich Schäffler, Tagungsorganisatoren

Condensed Matter (KOND)

At the annual meeting in Linz, the KOND section of the SPS organized 4 parallel sessions and a plenary talk covering the wide range of activities in condensed matter research: Magnetism, superconductivity, and quantum criticality and neutrons and synchrotron radiation for condensed matter on Wednesday; for the first time a shared session with

5) Lisa Kaltenegger MPI Heidelberg, 6) Douglas Cripe, GEO Genève, 7) Rainer Wallny, ETH Zürich, 8) Silke Bühler-Paschen, TU Wien, 9) Primoz Ziherl, Uni Ljubljana.

Fruitful discussions between participants and exhibitors ...



... as well as during the postersessions ...

... with the right refreshment for a warm summer evening.

Pictures in this article: p. 5 top and bottom left: © Nina Hrauda, JKU; p. 6-7 bottom row 1, 2, 5, 6, 7, 9: © Julian Stangl, JKU; all other pictures: © SPS

biophysics on soft matter systems and one on semiconductors on Thursday; and on Friday afternoon a session dedicated to condensed matter computational and theory. Invited speakers in these sessions where equally distributed between the two countries, with a number of younger researches presenting their most recent work. Among those, Dr. Johan Chang from EPF Lausanne summarized a number of breakthroughs, which he and his collaborators achieved by neutron and X-ray scattering and spectroscopy techniques on high-temperature superconductors. Prof. Andreas Läuchli from the University of Innsbruck presented quantum phases of exotic spin models, which he studies with numerical methods and which may soon be observed in a number of model systems like magnets or cold atomic gases. The total of 40 oral presentations and a dozen posters show the strong activities in both countries in all areas of condensed matter physics. Furthermore, two recipients of SPS prizes demonstrated the importance and emergent topics of the field. Titus Neupert received the ABB prize and presented his theoretical work on topological insulators in an excellent and well-attended award talk on Friday morning; Jelena Klinovaja was awarded the IBM prize for her study of exotic bound states in low-dimensional conductors and presented her findings to a broader audience during a very clear talk in the condensed matter theory session Friday afternoon. Both are now working as postdoctoral researchers/fellows in the US. Also on Friday, Prof. Silke Bühler-Paschen from TU Vienna presented the plenary talk "Quantum Phase Transitions in Condensed Matter", which, after an excursion into the high-energy LHC physics by the speaker before, guided the audience across many orders of magnitude in energy scale to temperatures near absolute zero and the exotic quantum phenomena occurring under such conditions in materials with strong electronic correlations and heavy electron behavior. Experimental studies of quantum criticality are a current frontier in condensed matter physics and require the development of new experimental methods that are applicable at ultra-low temperatures, the preparation of high-quality samples, and further progress in the theoretical modeling of such phenomena. The KOND section of the SPS was also involved as co-organizer in sessions of the Neutron and Synchrotron Radiation (NESY) as well as Surface, Interface and Thin Film sections of the ÖPG, which do not have separate representatives in the SPS. The strong interest in both topics and large respective communities in both countries motivate such sessions also at future joint meetings, e.g. organized together with the Swiss Neutron Scattering Society.

Christian Rüegg

TASK 2013: Nuclear, Particle and Astrophysics

The 2013 session on Nuclear, Particle and Astrophysics, organized together with Eberhard Widmann from the Austrian Academy of Sciences, had a very rich program. No less than 31 talks and 10 posters were presented in the parallel sessions, including 3 overview talks on latest results from the IceCube neutrino observatory (A. Christov), spectroscopy of antihydrogen (C. Malbrunot) and ultracold neutrons (B. Lauss).

Another highlight was the presentation of Claudia Lederer,

laureate of the Viktor-Hess-Price of the ÖPG, on measurements of neutron capture on heavy elements, which are relevant for stellar nucleosynthesis. Half of the parallel sessions were devoted to results from the very rich physics program of LHC experiments, on Higgs physics, heavy quarks, searches for phenomena beyond the Standard Model, as well as instrumentation issues. This large spectrum of physics was also covered by the plenary presentation by Rainer Wallny from ETH Zürich, summarizing results from the first three years of data taking at LHC, with the discovery of the Higgs particle as the obvious highlight, now supplemented by a more and more detailed assessment of its properties. The physics of protons and neutrons was well covered, with detailed accounts of experimentation with antihydrogen, cold neutrons and beta decay.
As usual in recent years, the presentations were very professional and interesting to a public beyond the closed circle of specialists. Many thanks go to the Austrian colleagues from ÖPG for their support during the preparation of the program and the meeting itself.

Martin Pohl

Careers for Physicists

A special session on "Careers for Physicists" was organized in collaboration between the section "Physik - Industrie - Energie" of the Austrian Physical Society (Doris Steinmüller-Nethl) and the section "Physics in Industry" of the Swiss Physical Society (Kai Hencken). It was the main aim of the session to show that physicists have a wide range of opportunities outside the academic career path. Bernhard Braunecker (Braunecker Engineering) showed that advanced manufacturing is an interesting field for physicists. The production processes are nowadays highly optimized in order to stay competitive; modeling in order to control the production processes is an interesting field to apply physical insight. Bernd Rinn (ETH Zürich) discussed the role of physicists in order to cope with the "big data avalanche". Providing the possibilities to process and make use of the large amount of data that is currently produced, e.g., in the life sciences, is only possible if scientists from different fields work together. Physicists with their good background in general science and a structured way of thinking are highly welcome in this area. Stefano Verginelli talked about his experience of 30 years of Technical Management in the IT industry. The curiosity and creativity that they have, has helped them to stay successful in this industry over a long time. Josef Siess (EUSPUG) discussed in an interactive presentation how physicists can make the first steps towards a successful career in industry. Practical advise on how to find companies and how to highlight the technical as well as non-technical skills one has acquired during the university studies was given. Istvan Daruk (JKU) showed the changes in the publication landscape in the last 100 years. Citation metrics play an important role, which lead to a strong hierarchy of the journals.

Kai Hencken

Earth, Atmosphere and Environmental Physics

This year the oral session was organised under the name of "Applied, Plasma- and Geophysics" and was chaired by Ivo Furno and Stéphane Goyette on Wednesday, September 4th.
The part on Geophysics gathered a variety of topics: among which the description of an integrated observation system to monitor characteristics of a physical environment, namely the Black Sea catchment, to the dissemination of information collected about. Spatial Data Infrastructure eases the provision of spatially-explicit data and knowledge as contributions to the Global Earth Observation System of Systems (GEOSS). This was further emphasised during the plenary talk on Thursday by Douglas Cripe on "Using Earth Observations for Integrated Water Resources Management" who stressed that our understanding of complex environmental systems is of paramount importance and can help reduce the loss of life and property from natural and human induced disasters. Then, a talk on the characteristics of some living organism's properties, i.e. wild mushrooms, to accumulate Cesium-137, as the other relatively long-lived artificial radionuclide from the global and the Chernobyl fallout, stressed the danger associated with fission products moving and spreading in nature. This talk also stressed that a good understanding of the properties of our physical environment along with the radioactivity is better achieved when both fundamental and geophysics are taken into account. This was followed by two numerical studies on the microwave propagation and absorption in heterogeneous rocks, and by the computations of atom evaporation rates using entropy production maximisation. This session demonstrated that a proper knowledge, theoretical and numerical, of the physical processes is needed to understand and predict change in the physical world in addition to the key role played by the observations to the dissemination of quality information.

Stéphane Goyette

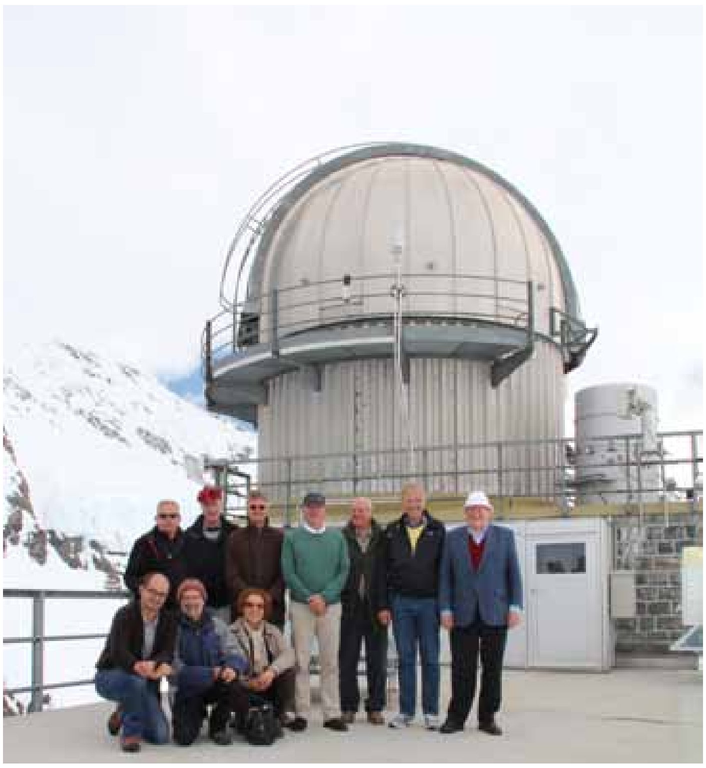
The final word ... from the two local organisers Armando Rastelli and Friedrich Schäffler.

News from SPS committee meetings (June & August) and the General Assembly

Not usual but well chosen, on 14-15 June the SPS committee met in the green and in the heights. This outdoors's meeting started in Grindelwald on Friday evening and was continued at the Jungfraujoch (JFJ) research station on Saturday. We dedicated the evening session to the theme "how to improve our Society", a brainstorming session which was a good opportunity to think on a larger basis than during the normal and compact bimonthly sessions in Bern. It resulted in a number of ideas on how to make our society stronger and more efficient.

Next day, inside the Forschungsstation Jungfraujoch, Martin Huber, president of the SCNAT-commission *HFSJG (Hochalpine Forschungsstation Jungfraujoch und Gornergrat)*, introduced us with a talk about the activities of this high altitude laboratory. These encompass - among others - meteorology (MeteoSwiss), Sun and Earth atmosphere (University of Liège), local detection of air pollutants and localisation of their geographical origin (EMPA) and aerosol

studies (atmosphere chemistry and cloud physics, PSI). We could visit the experimental installations in the Sphinx-observatory, guided by Erwin Flückiger, president of the *International Foundation for the Research Station JFJ*, responsible for the infrastructure. The scientific program is lead by Markus Leuenberger, director of the research station.
Thus the HFSJG is a prime site for the delivery of important data to the "Global Atmosphere Watch" program of the *World Meteorological Organization* (WMO). The atmosphere research on JFJ goes therefore along three main lines: the investigation of natural phenomena, the monitoring of atmospheric composition and finally research for policy support.



A permanent exhibition for the public on the research station activities at JFJ was organized by Martin Huber. It displays videos and explanations about the works in this unique laboratory and is set up near the elevator going to the Sphinx-Observatory.

Let us remember two emblematic results of the long-term climatological records measured at JFJ:
1) since the begin of the measurements at JFJ in 1933, the temperature increased by ~1.4°C,
2) since 1961, there are 60% more days with T>0°C (during 24h).

Annual Meetings: The date of the next SPS annual meeting in 2014 in Fribourg is now precisely fixed from Monday 30 June to Wednesday 2nd July. It will be held jointly with the NCCR MUST (Molecular Ultrafast Science and Technology), the Association MaNEP (emerged from the former NCCR MaNEP) and the Swiss Institute of Particle Physics CHIPP.

After the successful workshop of the YPF (Young Physicists' Forum) in Macolin this year on "Physics and Sport", the students are willing to organize a similar event in 2014 on a new theme, together with a seminar, visits and excursions.
SCNAT is promoting the sponsorship (Patenschaft, parrainage) of secondary students in their maturity work, see *http://www.scnat.ch/d/Fokus_Jugend/Patenschaft_fuer_Maturaarbeiten/index.php?*. One should remember how formative such personal work is and the role it plays in the choice of a formation. The demand is addressed to each physicist!

At the last Council of the European Physical Society (EPS) our German colleagues from the DPG reported on the implications to the teaching in German schools of the "Karlsruher Physics Course" (KPC), which was introduced in Germany in the 70'ties. A reminder of what the KPC is all about and its dissemination in the German part of Switzerland was discussed in the SPS committee meeting together with a colleague from didactics, as well as with a representative from the German Swiss Physics Commission (DPK) and from the Swiss Association of Mathematics and Physics Teachers (VSMP). It was decided to follow-up on this topic at a later stage in a common workshop.

The **General Assembly** was held on Sept 5 in Linz, after the plenary session. The president, Andreas Schopper, reminded in his review some basics about the SPS like its relations with several academies and international organisations as well as the associate memberships of universities and other institutions with the SPS.

The many activities like seminars and workshops (see announcements and reports in previous issues of the "SPS Communications") were mentionned. The intention of continuation and development of such activities in the next years was emphasized, seeing for instance, after a successful start with a workshop at CERN, a need for "Lehrerfortbildung" in other modern research topics.
The SPS will also contribute to the bicentennial of SCNAT and the International Year of Light, both in 2015.

The president announced a new SPS award sponsored by METAS, starting in 2014 (see p. 14). Furthermore some of the ongoing activities (mentionned above) were addressed.

Three new committee members have been elected (see below). The assembly warmly thanked our leaving committee members, in particular Ivo Furno, Chair of the Applied Physics section, leaving after six years of excellent services. Christophe Rossel, our former dynamical president and vice-president, will happily continue to participate as SCNAT delegate.

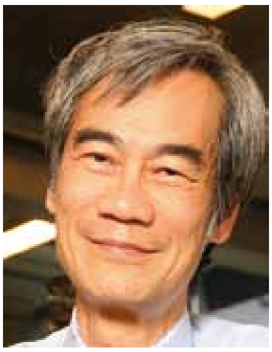
It is also the place here to warmly thank Susanne Johner for the quality of her "Protokolle" which she wrote for many years, a great help for an efficient work of the committee. Her successor will be Edith Grüter from EPFL.

The minutes of the General Assembly will be published in the SPS Communications No. 43.

Antoine Pochelon, SPS Secretary

New SPS Committee Members

Prof. Dr. Minh Quang Tran (Vice-President)



Minh Quang Tran studied physics at the Ecole Polytechnique Fédérale de Lausanne (EPFL) and received his diploma of "Ingénieur Physicien" in 1973. He did his PhD at the Centre de Recherches en Physique des Plasmas (CRPP) of the EPFL (1977). After two years of post-doc at the University of California, Los Angeles in Plasma Physics, he returned to the CRPP and occupied various responsibilities as head of the Basic Plasma Physics Group, of the high power microwave source ("gyrotron") development (in collaboration with industry). He was in charge of the implementation of the heating system of the CRPP tokomak TCV.
In 1992 he became Professeur Titulaire at the EPFL, and in 1993 Vice-Director of the CRPP.
He was nominated Full Professor at the EPFL in 1997 and became Director of the CRPP in 1999.
From 2003 to 2006, as "EFDA Leader", he was responsible for joint development by European laboratories in the field of fusion. His research interests encompass development needed to realize fusion as energy source.
M. Q. Tran is fellow of the Institute of Physics, elected member of the Swiss Academy of Technology and Science (SATW) and of the Academia Europea. He is presently also Vice-Chair of Fusion Power Coordinating Committee of the Paris based International Energy Agency. He has served in numerous European and International Committees in the field of fusion.

"I am very honoured that the SPS elected me as Vice-President. I am looking forward to serve the Society and the associate and individual members. Every citizen is confronted with more and more complex societal issues with interlinks between science and politics: I see our Society playing a key role not only in the physics community, but also in the scientific community at large and the whole society."

Dr. Stephan Brunner (Chair of the Applied Physics Section)

Stephan Brunner received his master's degree in physical engineering from the Ecole Polytechnique Fédérale (EPFL) de Lausanne in 1992. He then joined the Centre de Recherches en Physique des Plasmas (CRPP, EPFL), where he helped initiate the laboratory's ongoing effort in studying turbulent transport in magnetic fusion relevant plasmas through first principle-based simulations. In relation with this work, Brunner received his PhD degree in 1997. During this same period, he was also involved in the numerical simulation of industrial plasmas.
Starting in 1998, Brunner was hired by the theory group of the Princeton Plasma Physics Laboratory (PPPL), New Jersey, first as a postdoc and then from 1999 as a fixed staff member. His main focus during this period was the numerical simulation of various phenomena in Laser Plasma Interaction (LPI) under inertial confinement fusion relevant conditions. To this end he developed a series of kinetic codes based on novel numerical methods for studying non-local electron heat transport as well as parametric instabilities. His work was carried out in close collaboration with researchers at the Lawrence Livermore National Laboratory (LLNL), California.
From 2001 to 2003, Brunner joined the former company Locus Pharmaceuticals, Philadelphia, specialized in small molecule drug design using a fragment-based approach. As a member of Locus' core development team for their proprietary simulation codes, he developed different methods for estimating binding affinity of small molecules to target proteins, as well as for identifying key fragments for building potential drugs with high affinity and specificity. This work led him to become author of a series of patents.

End of 2003, Brunner returned to the CRPP in Lausanne, where he resumed his research both in the field of magnetic and inertial fusion relevant plasmas. His main current research focus is the further development and application of ever more realistic non-linear, gyrokinetic codes, running on some of today's most powerful high performance computers. On this subject, he in particular works in collaboration with researchers at the Max Planck Institute für Plasma Physik, Garching, Germany. Brunner is further pursuing his work on LPI together with colleagues at LLNL. He is also the supervisor of PhD students and is a lecturer in the frame of EPFL's doctoral school.

PD Dr. Hans Peter Beck (Co-Chair of the Section "Education and Promotion of Physics")

Hans Peter Beck is a member of the ATLAS collaboration at CERN and lecturer at the University of Bern, teaching physics for undergraduates and master students. After graduation at the University of Zürich in 1991, he joined the H1 collaboration at the Hadron Electron Ring Accelerator (HERA) in Hamburg, Germany, to study head-on collisions of electrons with protons at high energies. He quickly became deeply involved in the trigger, the on-line selection system to filter out interesting collisions from the majority of those that do not offer the potential to reveal new physics insight. He has earned his PhD in 1996 on a measurement of total cross section of high energetic photons-proton interactions. For this he used photons that radiate off from electrons and letting these collide head-on with the incoming protons in the HERA accelerator.
Hans Peter Beck joined the Laboratory for High Energy Physics at the University of Bern in 1997 and also joined the ATLAS Collaboration at CERN's Large Hadron Collider (LHC), long before first collisions took place. He became pivotal in the design and implementation of the ATLAS trigger and data acquisition system of the ATLAS detector, and is now concentrating on physics studies of proton-proton collisions provided by the LHC and measured with the ATLAS detector.
He contributed especially into the physics of colliding protons where multiple leptons are produced at large transverse momenta, as is in the case of electroweak processes involving W and Z bosons and of most actual relevance in the decay of the Higgs boson. During the last two years, he was intimately involved in the Higgs to four lepton decay mode, via exchange of two intermediate Z bosons, that finally has contributed to the recent discovery of a new boson at CERN.
Hans Peter Beck is involved in public outreach activities where he is conveying to teachers, students and interested laymen the quest of particle physics in finding answers to deep questions such as "*What are the origins of mass?*", or "*How did the universe begin?*". He is member of the CHIPP board and responsible for its outreach activities and he is also co-chair of the International Particle Physics Outreach Group (IPPOG). He brought the IPPOG masterclasses in particle physics to Bern, where every Spring 20-30 high-school students become particle physicists for a day. He is the initiator of "Verflixtes Higgs", supported by SERI (State Secretariat for Education, Research and Innovation) and of "*Interactions – Swiss particle physicists initiate a dialogue with society*", supported by SNF/Agora.
http://www.particlephysics.ch

Obituary for SPS Honorary Member Øystein Fischer

Prof. Øystein Håkon Fischer, Honorary Professor at the University of Geneva, initiator and founding Director of the Swiss National Center of Competence in Research MaNEP - Materials with novel electronic properties - dedicated to exploring electronic materials of the future, passed away on 19 September 2013 at the age of 71.

Photo credit : Lionel Windels (2012).

Øystein Fischer was born on March 9, 1942 in Bergen, Norway, where he went to school and grew up. His interest for science became obvious very early on, when he set up a small chemistry laboratory under the stairwell in his parents' house to mix various smelly and exploding cocktails. His scientific career started as a technical assistant at the research laboratory of Nera A/S in Bergen, Norway. In 1962, he moved to Switzerland to study physics at the Swiss Federal Institute of Technology in Zürich. There, he obtained a Diploma degree in theoretical physics in 1967, under the guidance of Prof. W. Baltensberger. He subsequently moved to the University of Geneva to join the group of Prof. M. Peter where he obtained, in 1971, his PhD degree in experimental physics. The same year he became an assistant professor in the Department of Condensed Matter Physics at the University of Geneva. He was promoted to full professorship in the same department in 1977. With characteristic humor, and with ardent commitment to innovation, he then became one of the "galopins" (scamps) in the department, a group of young professors with novel and bright ideas formed as a counter-weight to long established colleagues in the department.

Øystein Fischer dedicated much of his career to studying superconductors, in an effort to understand their fundamental properties, and to develop new materials for applications. In 1975, he synthesized the first superconducting compounds (Chevrel phases) containing a regular lattice of magnetic ions (Europium) - a discovery which launched a decade of international research concerning the interaction between magnetism and superconductivity. This research culminated in 1984 with his discovery of magnetic field induced superconductivity in these same materials. This result was the first confirmed experimental evidence of the Jaccarino-Peter effect predicted in the sixties.

His scientific work took a sharp turn with the discovery of high temperature superconductivity (HTS) in the cuprates in 1986. He was on a one year visit as a Theodore H. Geballe professor at Stanford University when Bednorz and Müller made their groundbreaking discovery. Realizing its importance, Øystein travelled tirelessly between Stanford and Geneva to steer the research of his team from Chevrel phases to HTS. Airplanes became his second home. He initiated a sustained effort growing the first artificial superlattices of HTS cuprates which contributed to the now rapidly developing fields of oxide thin film heterostructures and oxide interface physics.

In 1986, Øystein Fischer introduced scanning tunnelling microscopy (STM) and scanning tunnelling spectroscopy (STS) to Geneva. The last two decades of his research mainly focused on applying this technique to studying HTS materials. He and his team succeeded in obtaining the first reproducible tunnelling spectroscopy measurements in HTS. This enabled them to observe the vortex cores and pseudo-gap in cuprate high-critical-temperature superconductors, highlighting the unexpected differences between these novel systems and classic superconductors. In 2012, Øystein Fischer was awarded the prestigious Kamerlingh Onnes prize for "leadership in magnetic superconductors and pioneering scanning tunnelling microscopy studies in cuprate high-T_c materials."

We both met Øystein Fischer as a teacher and fantastic mentor. Today, we mourn the loss of a valued colleague and a very dear friend. He was a relentless and contagious enthusiast. Spending an hour in his office after frustrating times in the laboratory struggling with difficult experiments was the best medicine. He was a nearly inexhaustible source of ideas, and had the art of making the most unlikely of all experiments look obvious. He was certainly the expert in motivating his team for scientific projects, conference organization or big plans for new developments in Geneva.

His engagement in the community has been truly remarkable. Between 1983 and 1989, he was Vice-president of the physics section in Geneva and later President of the section for 3 years. Between 1998 and 2004, he was the Vice-dean of the Faculty of science. He has also been a member of the National Research Council of the Swiss National Science Foundation for many years.

In addition to his remarkable activities in research, Øystein's relentless commitment to physics in Geneva, and condensed matter physics in Switzerland and internationally was known to all. His drive as the director of MaNEP led to a remarkable development of collaborations between scientists in industry and academia. Never short of ideas, he explored different avenues to share his passion for science. He has been the initiator of the PhysiScope - an amazing platform allowing school students of different ages to participate in a selection of scientific adventures - as a way to share enthusiasm for research, and make known to the youngest the fabulous scientific challenges that we face. He teamed up with Swiss artist Etiennne Krähenbühl to create an artwork staging superconducting levitation. Presented alongside a scientific exhibition, this sculpture has proven a unique way to reach a new public normally not attracted to science.

Committed to promoting local community development, Prof. Fischer was the initiator of the Geneva Creativity Center, which aims to stimulate exchanges between the academic and industrial sectors, and to find solutions for the most challenging technological issues modern society is facing. He was also head of the project for 'The Centre of Astronomical, Physical and Mathematical Sciences' in Geneva, one of the leading projects of the University of Geneva. His vision for the future, and the energy that he was able to put towards causes he championed were clearly exceptional.

Øystein Fischer was a very talented and much appreciated teacher. He trained many undergraduates, PhD students and postdocs. He received numerous awards and distinctions for his research, including 'Doctor honoris causa' from the University of Rennes in 1990; the Gunnar Randers Research Award in 2005; 'Doctor honoris causa' from the University of Neuchâtel also in 2005; and the endowed 'Tage Erlander' Chair from the Swedish Council for Research in 2009. He became honorary member of the SPS in 2010.

The involvement of Øystein Fischer, the numerous projects he launched, and the ones still to be completed are a fantastic legacy for his younger colleagues in Geneva. We will certainly continue pushing to further develop the initiatives proposed by Øystein Fischer, and to convey as much energy, passion and enthusiasm as he did.

Christoph Renner and Jean-Marc Triscone
MaNEP-DPMC
University of Geneva

Neuer SPG-Preis für Arbeiten mit Bezug zur Metrologie - Nouveau prix de la SSP pour des travaux de recherche faisant référence au domaine de la métrologie

Das Eidgenössische Institut für Metrologie METAS (*www.metas.ch*) stiftet ab 2014 einen SPG-Preis für eine hervorragende Arbeit, welche einen Bezug zur Metrologie hat.
Das METAS hat als nationales Metrologieinstitut den Auftrag, dafür zu sorgen, dass in der Schweiz mit der Genauigkeit gemessen und geprüft werden kann, wie es für die Belange von Wirtschaft, Forschung und Verwaltung erforderlich ist. Es steht an der Spitze der Messgenauigkeit in der Schweiz.
Eine gute metrologische Infrastruktur ist für die industrielle Produktion, den Handel, die öffentliche Sicherheit, Gesundheit und Umwelt wesentlich. Metrologie spielt aber auch für die Wissenschaft eine wesentliche Rolle: Die physikalische Forschung, insbesondere auf neuen Gebieten, ist in hohem Masse auf angemessene messtechnische Grundlagen und Verfahren angewiesen. Der Nobelpreisträger Lord Kelvin hat diese Tatsache einmal pointiert formuliert: "When you can measure what you are speaking about and express it in numbers you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."
Der vom METAS gestiftete Preis soll auf die grosse Bedeutung metrologischer Fragestellungen hinweisen und junge Forscher zur Auseinandersetzung mit ihnen anregen.

L'Institut fédéral de métrologie METAS (*www.metas.ch*) offre, à partir de 2014, un prix de la SSP pour un travail de recherche d'une qualité exceptionnelle faisant référence au domaine de la métrologie.
En tant qu'Institut national de métrologie, METAS est chargé de veiller à ce que les mesures et les essais réalisés en Suisse soient conformes aux exigences d'exactitude de l'industrie, de la recherche et de l'administration. METAS se trouve au sommet de la pyramide de l'exactitude de mesure en Suisse.
Une excellente infrastructure métrologique est essentielle pour la production industrielle, le commerce, la sécurité publique, la santé et l'environnement. La métrologie a aussi une grande importance pour la science: La recherche dans le domaine de la physique est dépendante des bases et procédures métrologiques adéquates, avant tout dans des domaines nouveaux. Lord Kelvin, le lauréat du prix Nobel de physique, l'a exprimé de manière particulièrement pertinente : « When you can measure what you are speaking about and express it in numbers you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. »
Le but du prix de la SSP offert par METAS est d'attirer l'attention sur la grande importance des thèmes métrologiques et d'inciter des jeunes chercheurs à s'y atteler.

Kurzmitteilungen - Short Announcements

Pre-Announcement: SPS Annual Meeting 2014

The next annual meeting will take place at the Université de Fribourg, June 30 - July 2, 2014.

CHIPP, NCCR MUST and the Association MaNEP will partake, ensuring again a high quality program. Further details will be announced in the next issue of the SPS Communications, to appear in early 2014.

We encourage you to already reserve the conference date in your agenda.

SATW Technology Outlook/Foresight

Swiss industry has been very successful to date. Yet, shifts in technology paradigms are becoming increasingly rapid as we enter the 21st century and have a deep impact on society and sustainability. Today, there is no expert platform in Switzerland, which systematically analyses and forecasts technological challenges that lay ahead and which could aid policy makers prepare for the future.
For this critical reason, SATW has decided to fill this gap and to generate and publish the report "Technology Outlook" (TO) bi-annually, starting in 2014. The report will be aimed primarily at governmental, political and industrial leaders. The content should be presented to attract the attention of these target groups and to launch a broad discussion among decision makers and also in the public. By doing this, SATW targets assuming a leading role in technology foresight in Switzerland.

The report will cover the following topics:
- Analysis and presentation of the technological trends and developments of greatest importance to the Swiss economy and Swiss society.
- Highlighting of possible development pathways for Swiss industry.

This project is the basis of the foresight process of SATW. The SATW Science Advisory Board is the responsible entity for this project. The study is prepared by members of the Scientific Advisory Board, assisted by selected experts from industry and science and supported by staff from the SATW Secretariat.

B. Braunecker

Vorträge in den Schulen – ein neues Angebot im Rahmen der Patenschaften für Maturaarbeiten

Lehrkräfte haben die Möglichkeit, Forschende einzuladen, um in der Schule über Naturwissenschaften zu diskutieren. Die Akademie SCNAT stellt ihnen dazu eine Liste an Expertinnen und Experten der gesamten Schweiz zur Verfügung, welche motiviert sind, in Klassenzimmern über ihr Fachgebiet zu sprechen. Dieses Angebot ergänzt die Initiative Patenschaften für Maturaarbeiten. Die Listen der beiden Angebote sind im Internet verfügbar unter *www.maturity-work.scnat.ch*. Zudem kann die neue gedruckte Broschüre bestellt werden bei *info@scnat.ch*.

Quelle: SCNAT Newsletter Oktober 2013

The 2013 Nobel Prize in Physics

Hans Peter Beck, Uni Bern

Award
The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2013 to **François Englert** and **Peter W. Higgs** "*for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider*".

The Brout-Englert-Higgs mechanism

Back in 1964, Robert Brout together with François Englert and, independently, Peter Higgs proposed a solution to a problem that has deeply plagued the understanding of weak and electromagnetic interactions. If elementary particles, the fundamental building blocks of all matter in the universe shall be described by quantum field theory obeying basic gauge symmetries, then all gauge bosons and also all fermions necessarily have to be massless. Evidently this is in clear violation to the observed mass spectrum of particles. The solution proposed by Brout, Englert and Higgs was to break these underlying basic symmetries in a specific way, such that the initial state of the universe obeys to such symmetries but quickly finds its ground state, away from its initial symmetric state [1-3]. This is similar to a pen standing on its tip, which presents a fully symmetric initial state under rotations around the pen's vertical axis. However, such a carefully prepared pen falls quickly in an arbitrary direction and consequently will find itself lying flat on the ground pointing to a now specific, but otherwise fully arbitrary direction, evidently breaking the initial rotational symmetry. Translating back to quantum field theory, the role of the standing pen is taken up by a two component complex scalar field, the Higgs field ϕ, postulated such to pervade throughout the universe. Further, this field ϕ needs to live in a potential with the potential well away from its initial state. A potential with the shape of a Mexican hat has exactly such properties as is illustrated in Fig 1.
A two component complex scalar field has four free parameters, as is easily recognized when adding up real and imaginary parts for both components. These correspond to four degrees of freedom that are added to the theory. When the field ϕ finds its ground state, three of these four free degrees freeze out and become the transverse polarization modes of the two oppositely charged W-bosons and the Z-boson. The mere existence of transverse polarization of a spin-1 vector particle is equivalent for it having gained mass, as Lorentz invariance for mass-less particles prohibits otherwise. One degree of freedom stays, which gives rise to an excitation mode of the field ϕ above its ground state; this excitation is exactly what yields the Higgs boson. Brout, Englert and Higgs have been first to formulate ideas on how to allow for massive gauge particles in quantum

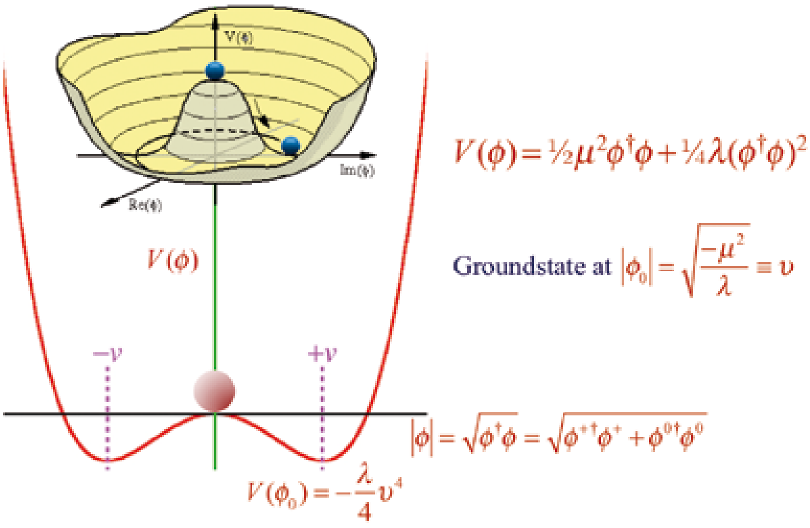


Figure 1: The Higgs potential resembles a Mexican hat.

field theories. More effort by people like Gerald Guralnik, Carl Hagen and Tom Kibble was needed to understand the properties of this mass generating mechanism [3]. Only after the ground-breaking work of Sheldon Glashow, Abdus Salam, Steven Weinberg [4-6], and of Gerard 't Hooft with Martinus Veltmann [7], symmetry breaking in a unified electro-weak theory could finally be settled. Electro-weak unification with a broken symmetry became a fundamental corner stone of the now very well established Standard Model of particle physics, with the other being quantum chromodynamics, the theory of strong interactions with unbroken symmetry. Unfortunately, Robert Brout passed away on May 3rd, 2011 and therefore could no longer be recognized by the Royal Swedish Academy who awarded two of the three discoverers of the Brout-Englert-Higgs (BEH) mechanism: François Englert and Peter Higgs and formally recognized the ATLAS and CMS experiments at CERN's Large Hadron Collider, who have confirmed the discovery of a new boson with properties consistent with those of the Standard Model Higgs boson on July 4th, 2012, see Fig 2.

Higgs Hunting

The BEH mass-generating mechanism allows for massive gauge bosons, today recognized as the W and Z bosons, the carriers of electro-weak interactions. Fermions also gain their mass via interacting with the all-pervading Higgs field ϕ, with massive fermions interacting more strongly with ϕ than less massive ones. In consequence, the interaction strengths of fermions with the Higgs boson *H* turns out to be proportional to their measured mass. Mass is thus a dynamic property of elementary particles due to their interaction with the Higgs field ϕ. Mass is truly distinct from other intrinsic properties of particles like charge or spin. This is also true for the Higgs boson itself, which owes its mass to its own interaction with the Higgs field.

The so completed Standard Model predicts all properties of the Higgs boson, except its mass, which however is bound from above and below from theoretical considerations. These are based on the simple fact that the potential well of the Mexican hat shaped potential needs to be finite and has to have its lowest value smaller than its value at its origin. Hunting the Higgs became a search over a wide range of possible Higgs masses between few tens of GeV to few hundreds of GeV. The dominant production and decay modes of the Higgs boson vary widely with the assumed Higgs mass, which became a free parameter throughout the searches. The search strategies have been tailored specifically for low, medium, and high Higgs masses. Direct searches of the Higgs boson and precision measurements of the W boson and top quark masses, which relate to the Higgs mass via quantum loop corrections, at the SPS, HERA, LEP and Tevatron accelerators were able to narrow down the still allowed Higgs range. These results were important ingredients in the design and building of the LHC, to definitely find the Higgs boson or to exclude it for good. An experimental confirmation of the non-existence of the Higgs boson would have been an equally fundamental result as its discovery. The all-pervading Higgs field would have been puffed away as the lumiferous ether was puffed away after the precision measurements of Michelson and Morley concluded in the ending 19th century giving way for a new relativistic interpretation of space and time. The Higgs boson, however, exists, and with it the Higgs field ϕ, pervading space throughout the universe.

Figure 2: François Englert, Peter Higgs and CERNs Rolf Heuer at the announcement of the discovery of a new boson in a seminar at CERN on 4th July 2012. Picture © CERN.

The Higgs discovery

The Large Hadron Collider, the 27 km circumference underground particle accelerator at CERN, straddling the Franco-Swiss border between the Jura-mountains and lake Geneva, collided protons on protons head on over the last three years at an initial center of mass energy of 7 TeV until the end of 2011 and of 8 TeV from April 2012 onwards. The ATLAS and CMS experiments, located at opposite sites of the LHC, were able to individually measure and decide online on every of the almost two quadrillion collisions (25 fb^{-1} × 70 mb = 1.75 × 10^{15} minimum bias collisions) offered to each of them whether the collision is worth while for further offline analysis. Those collisions that were retained underwent careful reconstruction and analysis to subsequently decide whether it contains a viable Higgs candidate. Less than a million Higgs bosons are expected of being produced in all these collisions, but only a few thousand of them decay in such a way to make a distinct feature in the experiments. There are three prominent decay channels for Higgs searches, where a Higgs decays either to a pair of high energetic photons, to a pair

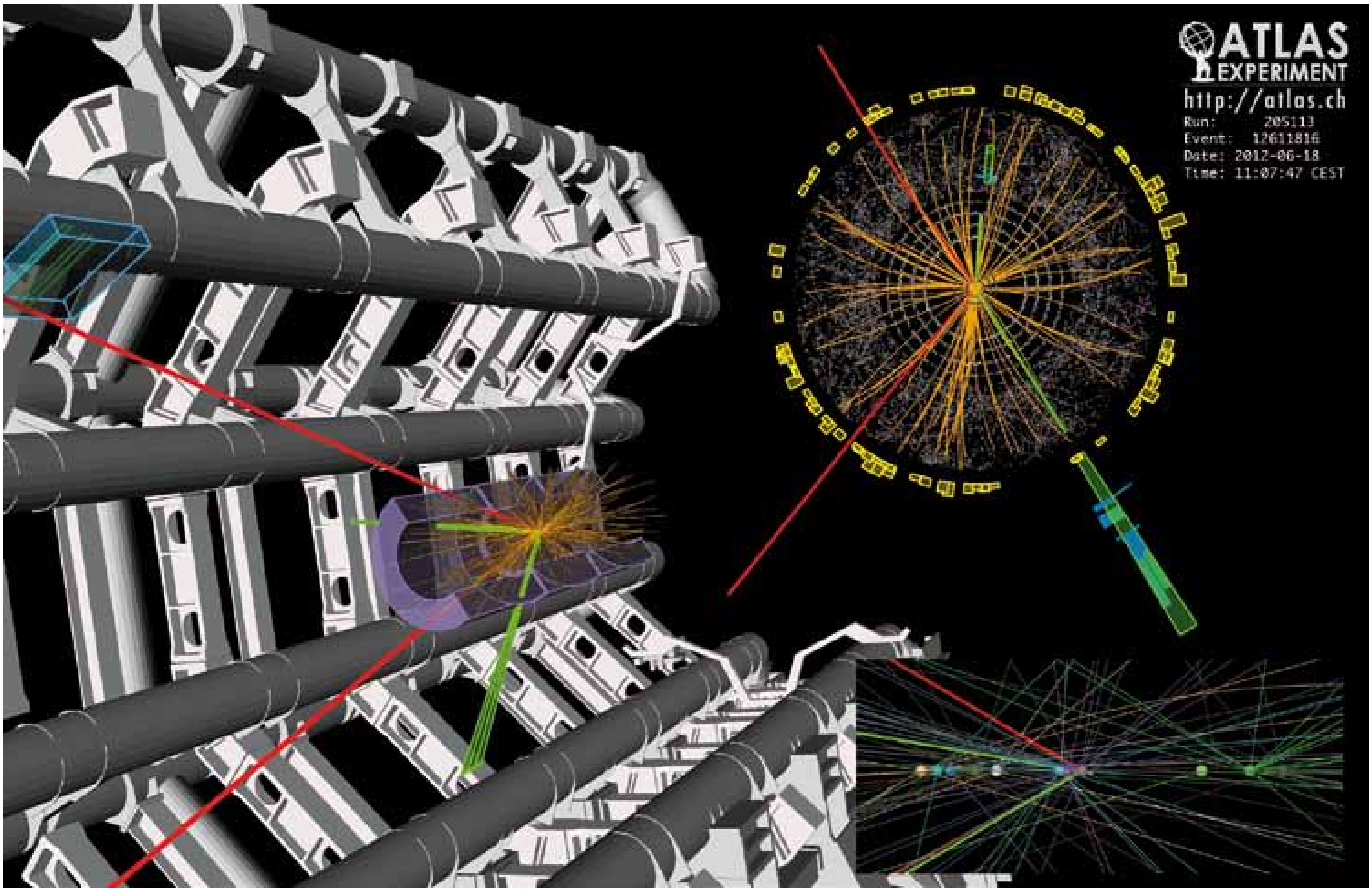


Figure 3: Event display of a $H \rightarrow ZZ^* \rightarrow 2e2\mu$ candidate event measured with the ATLAS detector. Muon tracks are colored red, electron tracks and clusters in the liquid argon calorimeter are colored green. The larger inset shows a zoom into the tracking detector. The smaller inset shows a zoom into the vertex region, indicating that the four leptons originate from the same primary vertex. Picture © CERN.

of Z bosons that further decay to two charged lepton pairs, and finally to a pair of W bosons that further decay each to a charged lepton and an escaping neutrino. All other decay channels of the Higgs are either too rare to be useful for discovery or too difficult to extract a non-ambiguous signal from the overwhelming background collisions at the LHC. ATLAS and CMS found clear evidence for a new boson at a mass of 125-126 GeV [9-10] that is produced in proton-proton collisions at the LHC and that decays into the various channels under consideration at about the correct rates. Figure 3 shows a Higgs candidate event, where the Higgs decays via two Z bosons into one pair of oppositely charged electrons and a second pair of oppositely charged muons. Figure 4 shows a Higgs candidate event, where the Higgs decays via an internal loop involving W-bosons and top quarks to two photons. Spin and parity as well as the coupling strengths of this new boson to W- and Z-bosons as well as to fermions have been inferred by both experiments and these agree with the for a Standard Model Higgs boson predicted values, within the today achievable precision [11-13]. The Swiss participation in the ATLAS and CMS experiments are with the Universities of Berne and Geneva participating in ATLAS, and the University of Zürich, ETH Zürich and PSI participating in CMS.

Standard Model or Beyond Standard Model?

All experimental results as of today indicate that indeed a Higgs boson has been found, which was reason enough for the Royal Swedish Academy of Sciences to award the 2013 Nobel Prize to Englert and Higgs. Whether the Standard Model is indeed the final answer to the mass generating mechanism or whether new physics has been found with the discovery of this new boson is still open to further precision measurements at the LHC. The actual planning for running the LHC foresees providing collisions to all its experiments over the next one and a half decades, increasing in both center of mass energy and collision rate allowing for a rich and far reaching physics programme. Today, about 1% of the prospected data volume has been gathered and that already gave experimental proof of the existence of a Higgs boson and therefore of an all-pervading Higgs field ϕ. The remaining 99% of data foreseen to be collected at the LHC will allow measuring the properties of this new boson with high precision, which will establish whether this new boson is indeed the last missing piece of the Standard Model or whether it is a door opener for new physics territory beyond the Standard Model, which could help answering open questions about the nature of Dark Matter or other ingredients of the universe.

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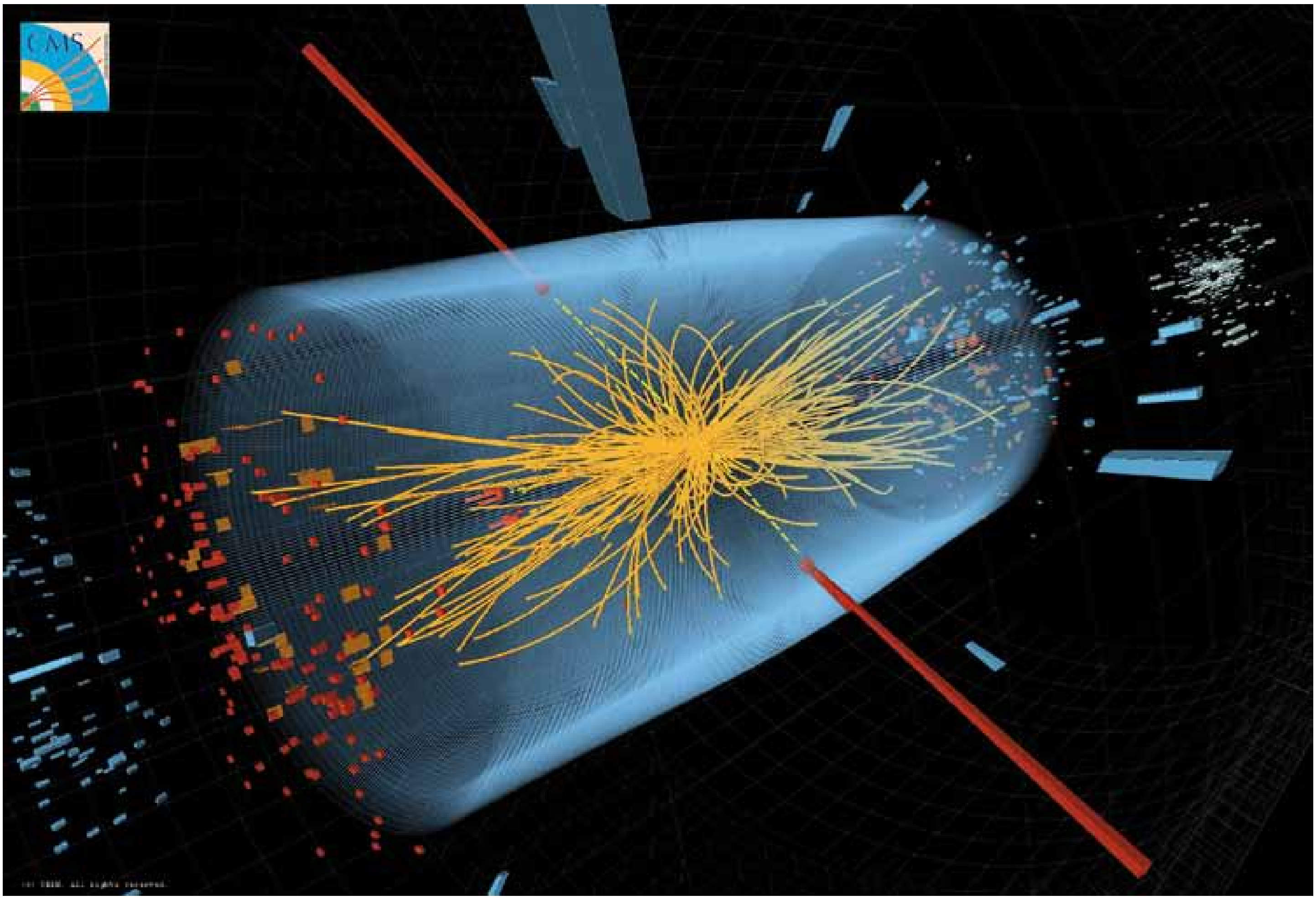

Figure 4: A typical candidate event including two high-energy photons whose energy (depicted by red towers) is measured in the CMS electromagnetic calorimeter. The yellow lines are the measured tracks of other particles produced in the collision. The pale blue volume shows the CMS crystal calorimeter barrel. Picture © CERN.

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Progress in Physics (36)

Modern Techniques in Radiation Oncology

Stephanie Lang and Oliver Riesterer

Introduction

Besides cardiovascular diseases cancer has become the major cause of death in the developed world. Between the ages of 45 and 84 years cancer actually is the number one cause of death in Switzerland. There are 37'000 new cancers diagnosed each year in Switzerland and 15'000 patients die of the disease. Statistically this equals about 63'000 potential life years lost for these patients (Bundesamt für Statistik; www.bfs.admin.ch). Because cancer is generally a disease of older people its importance will further increase in the next decades because of increasing life expectancy.
The main pillars of cancer treatment are surgery, radiotherapy and chemotherapy. Today patients usually receive multimodal treatments that include at least two or all three modalities. During the course of their disease 50-60% of all cancer patients will be treated with radiotherapy at least once, which underlines the importance of the discipline. Modern radiation oncology looks back on more than a century of developments. The beginning lies in the late 19th century when within a couple of years several ground breaking discoveries were made such as x-rays (Röntgen 1895), natural radioactivity (Becquerel 1896) and the first radioactive element radium (Curie 1898). Almost immediately the biological effects of the novel rays were recognized and no later than 1896 the Viennese physician Leopold Freund published a paper about the successful treatment of a skin cancer with x-rays. In the early days as well as today, both, x-rays as well as γ-rays, are used in medical treatments. More recently also charged particles, mostly protons but also heavier particles such as carbon ions, have been used for patient treatments. Two principle methods exist to deliver the dose to the patient: In brachytherapy (=radiation from short distance) the radiation source is placed inside the body of the patient in close proximity to the tumor or even within the tumor whereas in external beam radiotherapy (EBRT) the radiation is pointed on a specific part of the body from outside. The following article is focusing on EBRT. Medically applied x-rays today are usually produced by linear accelerators (see information box) and protons or other charged particles are produced by cyclotrons or synchrotrons.

Physical, chemical and biological effects of high energy x-rays and charged particles

The physical effects of high energy x-rays as well as charged particles in matter (e.g. human tissue) are indirect and direct ionizations of atoms. X-rays are mainly indirectly ionizing by producing high energy electrons, when they interact with matter. The three main interaction processes are: Photoelectric Effect, Compton Effect and Pair Production. In the MeV - range that is most commonly used in radiation-oncology the Compton Effect is predominant. The high energy electrons have enough energy to produce a large number of ionizations by collisions. Charged particles on the other side are directly ionizing.
As the beam enters the matter (patient) the absorbed dose varies with depth. For photons in the MeV - range the largest dose is absorbed approximately 1.4 - 2 cm below the surface, then it falls off continuously (blue curve in Figure 1). The absorbed dose of the charged ions is relatively low between the surface and the point where they stop. The velocity of the heavy particles decreases continuously up to the end of their range, where they stop moving and generate a dose peak, the Bragg peak. After the Bragg peak the dose falls to close to zero within a few millimeters (red curve in Figure 1).

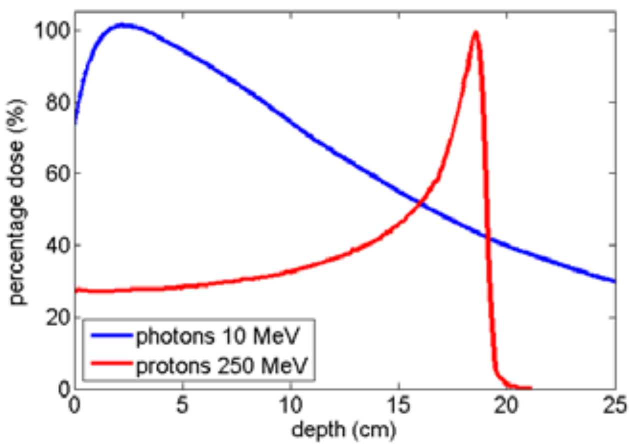

Figure 1: Dose distribution of high energetic photons and protons in water.

The major biological effect of ionizing radiation (IR) is DNA damage, e.g. when a secondary electron or a charged particle ionizes directly DNA molecules or indirectly by hydroxyl radicals (OH^-) that interact with DNA. Hydroxyl radicals are produced as a result of the ionization and chemical reaction of water molecules. By giving 1-2 Gy to a tumor more than 1000 single strand breaks and approximately 40 double strand breaks of the DNA double helix are induced per cancer cell. This damage could theoretically be repaired by the cellular DNA damage repair system. Because cancer cells are in many ways altered and abnormal, e.g. they divide more often and therefore are more vulnerable and they often have defective repair systems due to mutations, they are much more sensitive to radiation than normal cells. The knowledge about the biological effects of IR at molecular level has increased dramatically in recent years and today it is known that IR not only induces DNA damage but in addition a multitude of responses on the cellular level and the level of the tumor microenvironment. For example IR can activate cell membrane receptors that mediate survival signals into the cell in order to protect the cells from radiation damage. Another mechanism is that radiation can induce secretion of proteins from the cell that stimulate production of blood vessels in order to maintain the tumor cells' supply

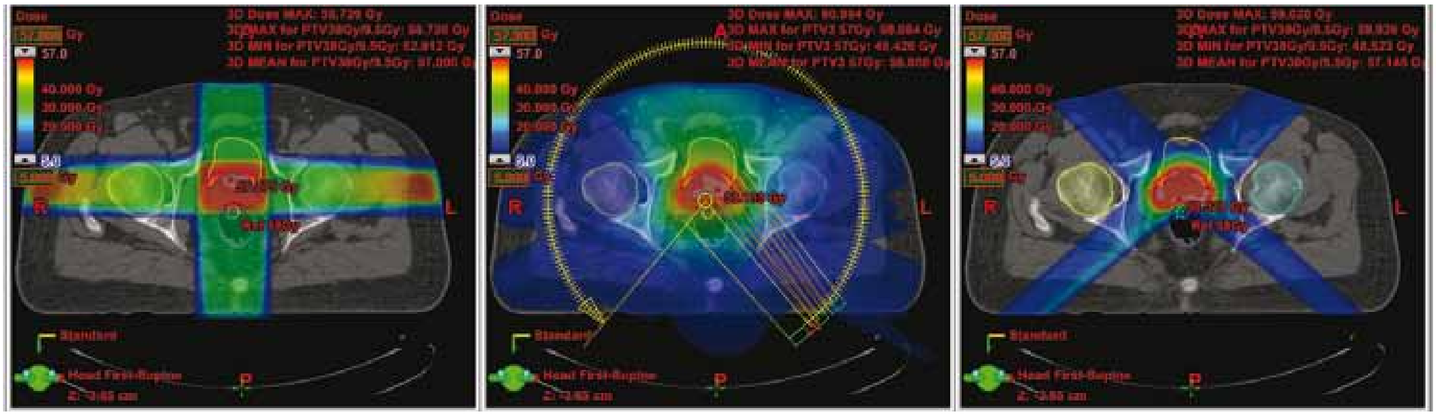

Figure 2: Comparison of treatment plans in a patient with prostate cancer. Shown is a typical slice of the planning CT in the pelvis with different radiation plans calculated: Left image: Conventional 4-field 3D-conformal plan; middle image: intensity modulated volumetric arc plan, right image: 4 field proton plan. The arrows show the target contour (prostate, red), the rectum (black with inflated rectum balloon) and the hips. Red volume signifies high dose, green volume intermediate dose and blue volume low dose. The rectum is the major organ that has to be spared from radiation in the case of prostate cancer. In order to protect the rectum an endorectal balloon is inserted before every radiation fraction and inflated with air. The rectum balloon serves to move major parts of the rectal wall away from the prostate and the high dose volume. The volumetric arc plan spares the rectum much better and conforms the dose better to the prostate than the 3D Plan. In comparison the proton plan shows equal target coverage as the VMAT plan but much less dose to the surrounding tissue, especially the rectum and both hip bones.

with oxygen and nutrients. In the clinical setting radiotherapy is often combined with classic chemotherapeutics in order to increase DNA damage (e.g. combination of IR and cisplatin that also induces DNA damage). A novel approach that is currently investigated in clinical and preclinical research is the combination of IR and molecular therapeutics, i.e. molecules or antibodies that counteract specific cellular or microenvironmental responses of the tumor (DNA repair, cell survival, angiogenesis = formation of tumor blood vessels etc.).

Elements of Modern Radiotherapy

The major elements of modern radiotherapy are diagnostic imaging, computer based treatment planning, treatment delivery (usually with a modern linear accelerator), and last but not least specialized personnel: doctors referred to as "radiation oncologists", medical physicists who are responsible for all physical aspects of treatment planning, treatment delivery, quality assurance and maintenance of treatment machines and radiation therapists, who usually are trained in treatment planning, practical aspects of quality assurance and to operate the treatment machines during patient treatment.

Treatment Planning

In the early days of radiation oncology only 2D treatment planning was possible. Based on anatomical landmarks and/or simple x-ray films the physicist calculated a 2D dose distribution in one slice plane of the patient. This treatment was not very conformal, i.e. the healthy tissue around the tumor could only minimally be spared. With the progress in information technology (hard- and software) and the invention of computed tomography (CT) modern 3D-conformal radiotherapy (3D-CRT) became possible and has been widely adopted since the 1980s. In the case of 3D-CRT a treatment plan is created on CT images using dedicated software that allows conforming the dose around the tumor and sparing the adjacent tissue. Before treatment planning the radiation oncologist defines the volume to be treated by drawing the target volume (GTV, gross tumor volume) on each CT slice. Usually a geometrical volume (PTV, planning target volume) is drawn around the GTV to compensate for positioning uncertainty of the patient and tumor. In addition the normal structures, that should be spared are drawn on the CT slices. Thereafter the radiotherapist prepares the treatment plan in close collaboration with the physicist. For 3D-CRT usually 2 to 5 beams from different angles and with different beam shaping profiles are used. Treatment planning became much more complex since the 1990's, when "intensity modulated radiotherapy" (IMRT) became available. In the case of IMRT the radiation beam is modulated at every time point by use of up to 120 dynamic and computer guided metal leafs introduced into the beam aperture. Intensity modulation allows improved conformity around the tumor and better sparing of surrounding normal structures. However it leads to an increase in the so-called "low dose bath", because of the increased scatter from the metal leafs, which might lead to an increase in secondary cancer. IMRT plans usually use multiple beams. Today most patients are treated with intensity modulated techniques. A variant of IMRT is volumetric modulated arc therapy (VMAT) where the LINAC rotates around the patient thereby applying hundreds of fields, by changing the shape of the metal leaf collimators and the dose per minute at each control point (depending on the vendor the control points are spaced between 2° and 5°). Figure 2 shows a comparison between a 3D-CRT plan and a VMAT plan in a patient with prostate cancer. Additionally the dose distribution, which can be achieved with protons is shown. As explained earlier protons (as other heavy ions) have the advantage that they deposit most of their energy in the Bragg peak. By adjusting the energy of the protons, in a way that the Bragg peak is in the tumor the healthy tissue can be better spared.

Treatment machines

The first linear accelerator was constructed in the 1950s and was basically a byproduct from Second World War radar technology. Later on, i.e. approximately in the 1970s, also particle therapy came up. Particle therapy uses immense installations to generate particle beams (usually protons but also heavier particles such as carbon ions) that, due to their physical properties, are able to deliver even more conformal radiotherapy than IMRT in selected cases. Switzerland with its proton facility at the Paul Scherrer Institute in Villigen has been pioneering proton therapy. Because the logistics of proton therapy are still immense with huge and expensive facilities it is still limited to specific indications such as pediatric cancers. In recent years several proton facilities opened all over the world and proton therapy has become more broadly available. Because proton therapy is still much more expensive than photon therapy and only few studies exist in patients its optimal use is still under debate. In Switzerland the construction of an additional proton facility is currently under discussion. In comparison, at least 55 linear accelerators are installed in 25 radiation centers.

Modern linear accelerators (box, figure 4) as well as proton treatment machines can deliver radiation therapy with sub-millimeter accuracy. Additionally they have integrated imaging systems such as computed tomography or MV image detectors introduced into the beam path allowing to identify the target in 3D shortly before and during treatment. This allows for very small safety margins between the actual tumor volume and the irradiated volume and ensures maximum sparing of healthy tissue.

Current Fields of Physical Research

As mentioned modern accelerators achieve sub-millimeter accuracy. However not all tumors are stable during the treatment session. Tumors in the lung can move up to 16 mm, in the liver up to 34 mm and the thoracic wall moves up to 14 mm due to respiratory motion. Prostate tumors move up to 9 mm mainly due to bowel motion and bladder filling. Tumor motion management to irradiate the tumor while sparing the healthy tissue is needed. There are different methods to manage tumor motion already in use and/or in development. First a motion encompassing treatment can be performed in which all tumor positions within the breathing cycle serve as target (Figure 3). Second treatment can be delivered gated, i.e. that the tumor is only treated in inspiration or expiration. Third the tumor is tracked which means that the beam follows the tumor. Tumor motion management is an important research topic for proton as well as photon therapy. However the interplay effect between the modulating beam and the moving organ is larger in proton therapy, leading to larger deviations between the planned and the delivered dose distribution. Therefore most protons centers currently don't treat moving tumors.

Tumor motion today can be imaged by 4-dimensional computed tomography (4D CT). Briefly, the respiratory curve of the patient is recorded during CT acquisition by means of an in-room installed infrared camera and a corresponding marker block put on the patient's chest. By use of a dedicated software the CT images are then sorted according to the respiratory phase and a 4D CT data set is generated. The development and clinical implementation of 4D magnetic resonance imaging similar to 4D computer tomography is another research topic currently under investigation.

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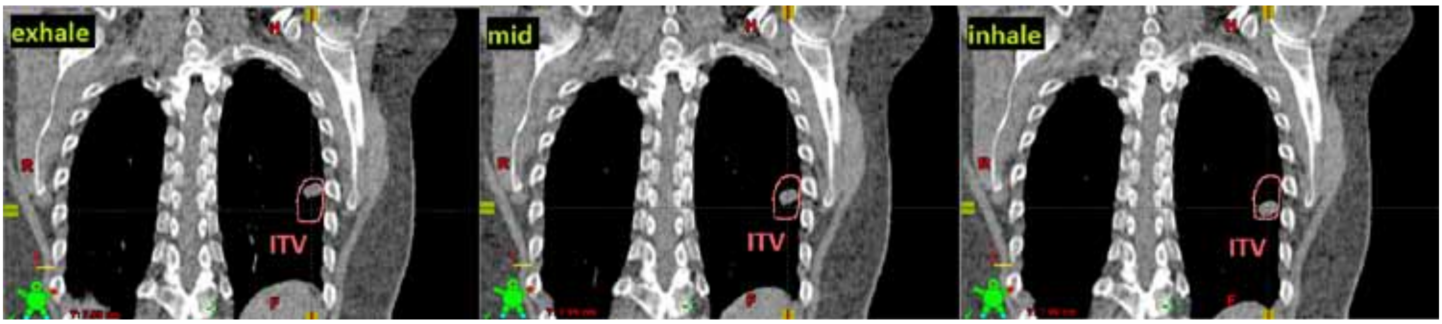
Stephanie Lang is Medical Physicist at the Department of Radiation Oncology of the University Hospital Zurich. Her clinical focuses are linear accelerator technology, dosimetry, quality assurance and stereotactic radiotherapy. Her main research interests are image-guided radiotherapy and motion management.



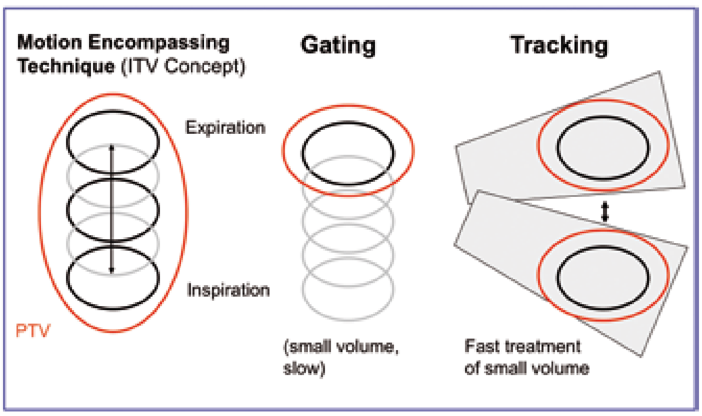


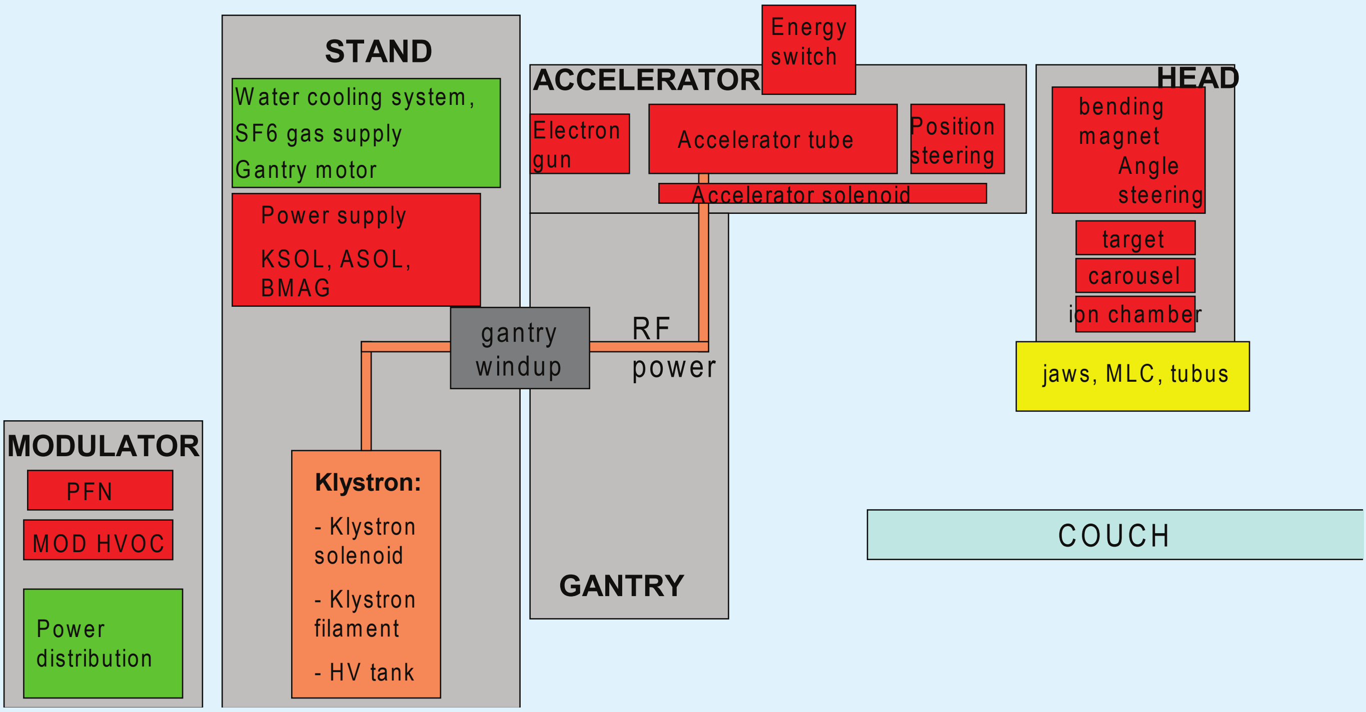
Figure 3a (top row): Coronal 4D CT slices of a patient with lung cancer. Shown are slices in expiration (left), mid ventilation (middle) and inspiration (right). The target volume (ITV = internal target volume) comprises all positions of the tumor within the breathing cycle.
Figure 3b: Methods of Motion Management: Left: Motion encompassing techniques (includes ITV as target volume). Middle: Gating: The tumor is only treated in deep inspiration or expiration. Right: Tumor tracking: The beam follows the movement of the tumor. With gating the treated volume is much smaller with less side effects but overall treatment time is prolonged because only a small part of the breathing cycle can be used for treatment (beam switches on and off).

A linear accelerator consists of 5 main parts:

- The modulator serves as a power supply for the linear accelerator.
- The stand is the non-rotating part that contains the cooling water supply and the klystron.
- The gantry is the rotating part of the linear accelerator. All beam generating and collimating parts are inside the gantry.
- The imaging system: Today most systems are equipped with high resolution imaging systems to correct the patient's position and orientation with respect to CT data, taken during planning phase.
- The treatment couch is used for positioning of the patient.

Figure 4 is a schematic drawing of a high energy linear accelerator, as it is installed at the University Hospital in Zürich. The electrons, emitted from a heated cathode and extracted by the anode field are properly focused by lens elements for injection into the accelerator tube. In the tube a standing high frequency wave (330 MHz) further accelerates the electrons to a maximum energy between 4 MeV and 20 MeV. The energy switch determines the length of the standing accelerating wave and therefore the energy of the electrons. After the energy switch the wave is phase shifted and cancels out so that it no longer accelerates the electrons. The klystron inside the stand produces the high frequency wave.
After leaving the waveguide, the electrons are bended by 270° and energy selected by one or multiple deflecting magnets. After hitting a tungsten target, high intensity Bremsstrahlung is produced. The beam intensity profile is anisotropic due to the forward scattering process and must be homogenized. First a primary collimator cuts out the central part of the beam, then a flattening filter, i.e. a metal cone with stronger absorption in the beam center than at the side lopes flattens the profile. The shape and flatness of the beam are monitored by two ionization chambers.
In order to radiate only the tumor and not the healthy tissue the beam profile needs to be shaped patient specifically. Several beam profile shaping devices are available. The jaws are used for the basic collimation of the beam, only square fields can be achieved using the jaws. The 120 metal multi leaf collimators are used to achieve more complex shapes.

The authors in front of the linear accelerator at the University Hospital in Zürich.



Progress in Physics (37)

Molecular Lego: Bottom-up Fabrication of Atomically Precise Graphene Nanostructures

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Conventional top-down structuring is reaching its limitations and is currently hampering the investigation of specific graphene nanostructures where quantum confinement and hence structural variations on the atomic level govern the electronic properties. On the other hand, bottom-up approaches relying on the colligation of suitable molecular precursors allow for the fabrication of prototypical graphene nanostructures with atomic precision and make them accessible for investigation of their physical properties.

A prominent system exemplifying the intimate relation between electronic and atomic structure is given by graphene. The electronic properties of graphene, a single atomic layer of graphite, are marked by some highly intriguing values such as a high charge carrier velocity (10^6 m/s), ballistic transport properties in the micrometer range at room temperature. Together with its structural stability, chemical inertness and optical properties (graphene absorbs only 2.3% of the light in very large spectral range while offering extraordinary electrical conductance properties [1]), this is currently motivating an impressive number of investigations that seek for possibilities on how to take advantage of these properties in various application fields. From a fundamental point of view, the Dirac-like equation describing the electronic properties of graphene where the carbon atoms are arranged in a honeycomb lattice gives access to the investigation of relativistic quantum phenomena in a benchtop experiment [2].

The whole richness of possible physical properties, however, is only accessible when considering specific nanostructures of graphene, i.e. when exploring the intimate relation between structural and electronic properties on a length scale where extreme confinement and interactions govern the properties of the charge carriers. Figure 1 shows two examples of graphene nanostructures: (i) specific shapes of graphene flakes with an imbalance between the number of carbon atoms belonging to the *A* and *B* sublattices, respectively, and (ii) narrow stripes of graphene, so-called graphene nanoribbons, that are described by a specific width and direction with respect to atomic lattice. For the first example, Lieb's theorem predicts a characteristic spin *S* that is relying on an imbalance between the occupation of the two structural sublattices: $S=1/2(N_A-N_B)$ [3]. The ability to structurally define such an imbalance thus holds promise for the design of pure hydrocarbons with a net magnetic moment. However, it requires the ultimate, namely atomic, resolution in their structure definition. The second example, graphene nanoribbons (GNRs), reveals that for low-dimensional systems, one of the major shortcomings of graphene, the missing electronic band gap, can be created when confining the electronic states to a very narrow width. Both examples show, however, that the atomic precision is needed in order to get predictable electronic or magnetic properties. For armchair GNRs (AGNRs), for instance, the band gap disappears when extending the width of a 7-AGNR (armchair ribbons with 7 carbon dimers across the width) by a single additional carbon dimer (Fig. 1c).

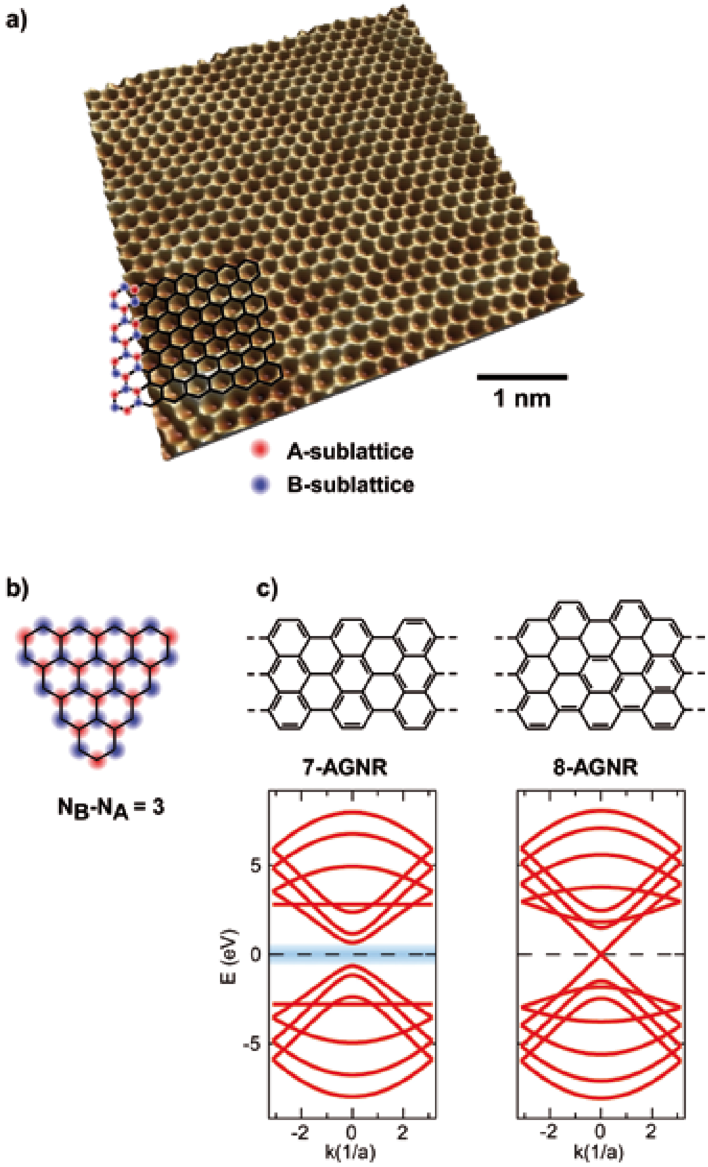

Fig. 1: Graphene-related structures. (a) Small-scale STM image of extended graphene grown on Pt(111) revealing the honeycomb-like atomic lattice. (b) Graphene nanostructure with a predicted magnetic moment due to the in inbalance in the occupation of A- and B-sublattices. (c) Graphene nanoribbon structures and their respective electronic band structure (tight binding) revealing semiconducting and metallic properties for 7-AGNRs and 8-AGNRs, respectively.

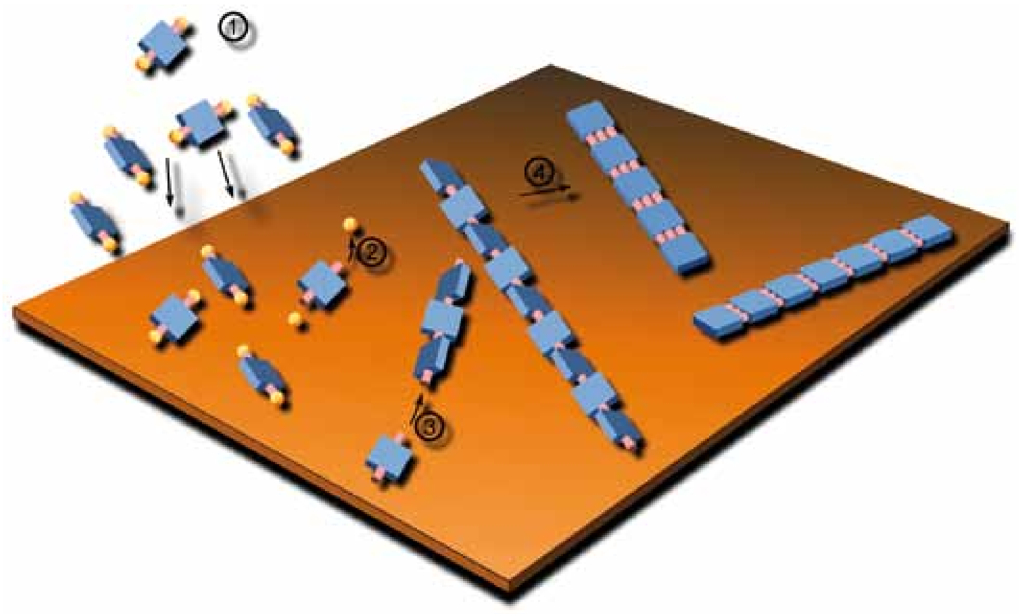

Fig. 2: Bottom-up fabrication concept for Graphene Nanoribbons: (1) Vacuum sublimation of precursor monomers on clean metal surface. (2) Surface-assisted monomer activation. (3) Oligomer formation by radical addition of diffusing monomers. (4) Planarization of the oligomer by intramolecular cyclodehydrogenation forming the final GNR.

Such resolution is, however, not accessible for traditional top-down structuring approaches. Comparing today's available resolution of e-beam lithography (10 nm) to the needed atomic precision (0.1 nm) is very much like trying to fabricate toothpicks with a motor saw. There is a factor of ~100 separating the actually needed and currently available structural resolution.

Bottom-up approaches, on the other hand, intend to fabricate such structures by using atomically precise building blocks, i.e. molecules or atoms, which then couple together to form extended structures with properties that are fully dictated by the properties of the precursor monomer. In order to do so, molecular building blocks furthermore need to have specific coupling sites that can be activated by an external stimulus in order to specifically colligate to the next structural subunits. Polymer chemistry has elaborated the needed chemical tools with great success and allows nowadays for the solution-based synthesis of organic materials with a vast range of properties. In view of graphene-related structures, such as carbon nanotubes, fullerenes and graphene itself, the solution-based bottom-up approach was until now not successful. Typically, graphene-related materials are fabricated by high temperature processes where a multitude of structural variants are produced, which then need, in a second step, to be separated in order to yield the desired structure.

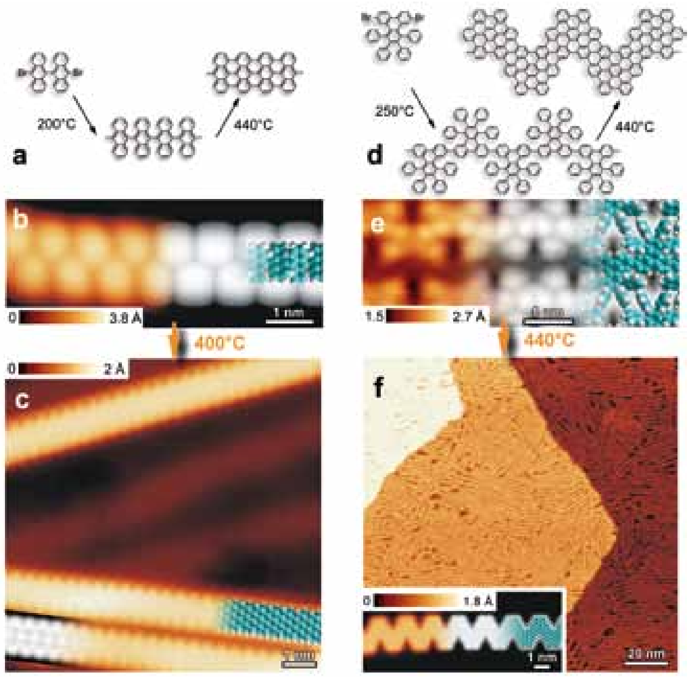

Fig. 3: STM images of the intermediate (top) and final step (bottom) during the bottom-up synthesis of two different types of GNR. (left) Fabrication of 7-AGNRs using a bianthryl-based precursor monomer. (right) Synthesis of chevron GNRs. Greyscale inserts are DFT-based simulations of STM images of the polymer and ribbon structures [4].

In 2007, the Grill group presented new concepts [5] allowing for the covalent assembly of molecular building blocks on surfaces. The work is based on the ability of introducing defined connection points onto the molecular building blocks that can be efficiently activated as soon as the molecules are adsorbed on a well-defined surface. The ability of organic chemistry to synthesize molecular building blocks with different number and relative position of predefined connection points allows for the construction of various topologies such as molecular dimers, linear molecular chains as well as two-dimensional arrays. This seminal work proved that the concept of 'molecular Lego' can be used for the fabrication of stable (since covalently bonded) and precise nano-architectures. Furthermore, this work has triggered numerous studies exploring possibilities to control specific chemical reactions on surfaces. Yet, this newly established research field of *on-surface chemistry* is not just about replicating known solution-based chemical reactions on the surface but much more about i) exploring the catalytic properties of the surface hosting the molecular species for the low-temperature activation of specific chemical reactions and ii) using the well defined conformation of molecular species adsorbed on atomically flat surfaces to get control on the activation of specific functional groups that are in close proximity to the surface, while others with larger distances remain unaffected. In a recent study [4], we have explored the possibilities of surface-assisted reactions for the bottom-up fabrication of GNRs. The main steps of the related on-surface synthesis protocol are sketched in Fig. 2. Experiments are conducted under ultra-high vacuum (UHV) conditions in order to be able to prepare and maintain clean surfaces and in order to be able to exclude reactions of the deposited molecular species with residual gas. The fundamental steps include (1) deposition of the molecular precursor on the metal surface by vacuum sublimation, (2) surface-assisted precursor activation by a first

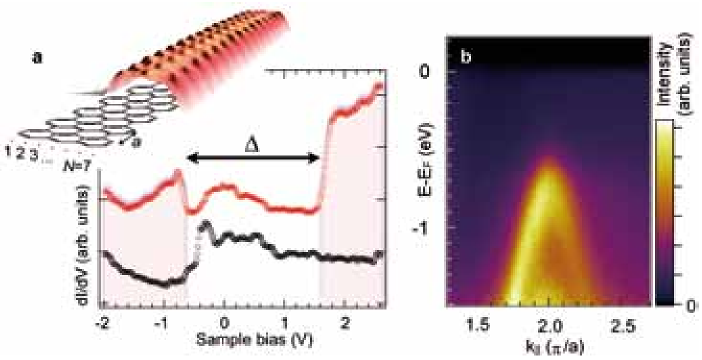

Fig. 4: Electronic structure determination of as-grown 7AGNRs. (a) Scanning tunneling spectra taken on the metal substrate (black) and on a GNR (red) revealing an electronic band gap Δ of 2.3 eV. (b) Angle-resolved photoemission spectroscopy of aligned 7-AGNRs. The highest occupied band is characterized by a low effective mass of 0.21 m_e and large slopes (and hence large charge carrier speeds of $8{\cdot}10^5$ m/s) in the linear band segments [6].

annealing step producing biradical species that (3) by diffusion along the surface covalently couple to each other by a radical addition process to form extended one-dimensional oligomers. For GNRs, an additional dehydrogenative step is necessary in order to transform the oligomers with single C-C bonds between the building blocks into the flat GNRs (4). It is clear that in order to follow and characterize the individual bottom-up fabrication steps, a method capable of resolving molecular conformations and separations with atomic resolution is needed. Scanning Tunneling Microscopy (STM) is ideally suited to give the needed insights in order to address possible unwanted reactions by changing reaction parameters or monomer design in order to get the desired GNR structure. STM images of intermediate and final structure of two different types of GNR [4] are shown in Fig. 3 and reveal that the bottom-up approach indeed allows for the targeted atomic precision of GNR fabrication. Accordingly, some prototypical GNR structures are now available for investigation of their electronic properties and to compare them to theoretical predictions. In a recent study [6], we determined the electronic structure of 7-AGNRs by means of Scanning Tunneling Spectroscopy and Angle-Resolved Photoelectron Spectroscopy (Fig. 4) and find a sizable band gap of 2.3 eV and a band dispersion that is in excellent agreement with theoretical predictions.

It is clear that similar fabrication strategies can also be used for the design of two-dimensional nanostructures. Examples along this direction are porphyrin-based nanoarchitectures [7], the synthesis of porous graphene [8] and triphenylamine-related macromolecular structures [9] that are all based on the activation and colligation of halogen-substituted precursor monomers. In order to reach even more diverse and complex bottom-up grown nanostructures, new types of on-surface reactions are currently investigated in different labs. These reactions include various dehydrogenation steps, imide and amide bond formation as well as Sonogashira coupling (for an overview see Refs. [10-12]) and show promise to establish a toolbox allowing for the surface-assisted fabrication of a rich variety of precise nano-architectures.

Future studies will furthermore have to tackle the problem of the metallic substrate that is currently needed as a catalyst for most of the used reactions. For the fabrication of prototypical devices relying on electronic or optoelectronic properties of the fabricated nanostructures it will thus be crucial to develop efficient but yet gentle process protocols allowing for their transfer onto insulating substrates.

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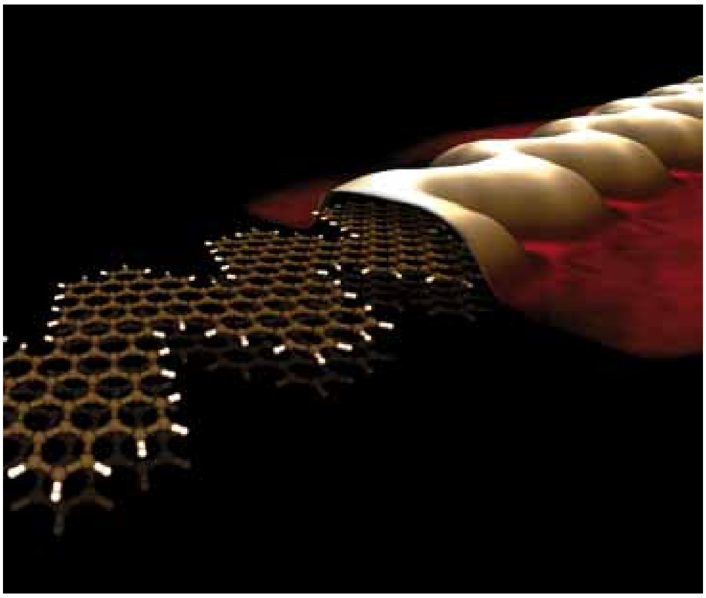


Bottom-up fabrication of atomically precise graphene nanoribbons. 3D representation of a scanning tunneling microscopy image and chemical structure of a chevron graphene nanoribbon. © Empa.

Milestones in Physics (2)

The fall of parity

Herwig Schopper, University Hamburg and CERN

In December 1956 a memorable colloquium took place at the Rutherford Laboratory in England: speaker Abdus Salam, chairman Wolfgang Pauli, with the title "Two-component neutrino theory". As a young researcher I could attend this historic event since I was spending a year with professor Robert Frisch (nephew of Lise Meitner) at Cambridge in UK who had sent me to listen to Salam's talk. What was so memorable about this colloquium? At the end of Salam's speech Pauli got up and apologised publicly to Abdus for having strongly discouraged him to publish his theory. The reason for the change of Pauli's conviction was that some rumours had arrived from New York reporting that C. S. Wu had done an experiment proving the violation of parity conservation. Although nobody had seen any results, Wu was known as an extremely careful experimentalist and hence this rumour was taken seriously.

The author in his lab, about 1960.

For Pauli who was surrounded by an aura of a very critical thinker and who was always very sure of himself, this was certainly not an easy gesture. Pauli had been convinced that parity had to be conserved whereas Salam's theory implied that it was maximally broken. The argument to which Pauli adhered was an almost philosophical one: since nature "does not know" whether we observe it directly or through a mirror, mirror reflection invariance must hold and hence parity must be conserved (according to Noether's general argument that each invariance implies a conservation law). The German philosopher Immanuel Kant had already argued that we must consider this as "denknotwendig" (necessary thinking) if we want to explore nature. Similar arguments apply for other quantities e.g. for the electric charge. What we call 'positive' or 'negative' was a purely arbitrary historical decision and since nature 'does not know' anything about it, exchanging all positive charges in the universe by negative ones and vice versa, is an invariance and electric charge must be conserved. Thus it seemed that parity violation had shaken our fundaments of understanding nature. In 1956 the contacts between West and East just started to be open after the cold war and when the famous Russian physicist L. D. Landau heard about parity violation his reaction was similar to that of Pauli. "Space cannot be asymmetric" was his statement. It is not surprising that this discovery found at that time a similar interest in the media as the Higgs discovery today. The lesson we should learn from the discovery of parity violation is that we should not trust even in the most obvious general principles unless they are verified by experiments.

It was not immediately recognised that also the particle-antiparticle invariance C was violated. When this eventually was realised, some theorists found an excuse for the surprising P violation by consoling themselves that the combined operation of mirror reflection and charge conjugation CP is the proper operation to be conserved, but without a good reason for such an argument.

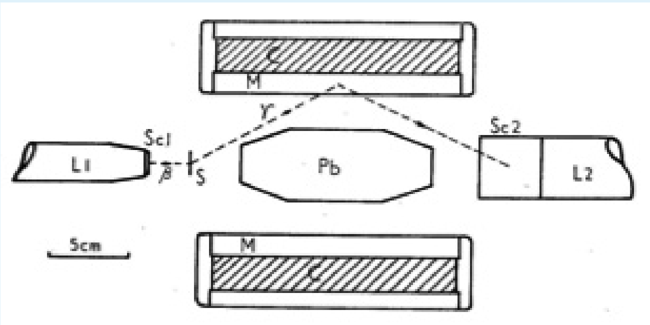
The colloquium where I had heard for the first time in my life about parity and its conservation, changed my direction of research. Back in the laboratory at Cambridge I studied during Christmas vacations the by now famous paper by Lee and Yang in which they proposed four experiments to check parity violation. One was the famous Wu experiment observing the asymmetric emission of beta-particles from polarised nuclei. A second experiment was the inverse, after the emission of a beta particle the remaining nucleus is polarised and if left in an excited state it emits a circularly polarised photon. Lee and Yang considered this experiment as unfeasible since they did not know of any way to measure circularly polarised photons. However, just before starting my visit at Cambridge I had done at my home university of Erlangen in Germany some experiments to measure the gamma-gamma circular polarisation correlations in nuclear decays using the photon scattering from polarised electrons in iron. So I knew how to do the 'unfeasible' experiment. I asked professor Frisch to allow me to perform it and immediately he promised to give me all the necessary support. In the machine shop I started to construct a cylindrical iron magnet to be used as a target of polarised electrons and Frisch managed to get me within a few days radioactive sources of ^{60}Co and ^{22}Na, the first decaying by electron emission (accompanied by antineutrino emission),

C. S. Wu and the author discussing helicities, about 1958.

the second a positron decay (with neutrino emission). In both cases I found within experimental errors a maximum violation of parity. At various occasions C. S. Wu mentioned later that this was the only experiment where it could be shown in the same apparatus that the helicities of neutrino and antineutrino are opposite and it was the first parity violation experiment in Europe. The publication had only one author who was technician, made the measurements, did the calculations for the size of the effect and wrote the paper within 5 weeks. What a beautiful time! Is this still thinkable today when experimental papers sometimes have several thousands of authors? The results were published in *Phil. Mag.* in February 1957 within several weeks (thanks to Otto Frisch who was editor) with those of the other 3 experiments proposed by Lee and Yang.

Parity

An experiment to observe parity violation must contain a helical quantity which changes sign under a mirror reflection. A helix is defined by a combination of a polar and an axial vector. In the famous Wu experiment ^{60}Co nuclei were oriented at low temperature (axial vector) and the momenta of beta particles (polar vector) observed in the direction of the nuclear orientation or opposite to it. The second experiment proposed by Lee and Yang is a reversal of the Wu experiment (see figure). One observes the direction of the emitted beta particle and after the beta decay the nuclei are oriented along this direction. If these nuclei emit a photon it becomes circularly polarised and its polarisation can be measured by Compton scattering from polarised electrons in iron. Since many nuclear beta decays are followed by a gamma, but only few nuclei can be oriented at low temperatures, this kind of experiment is adequate to study various problems. Thus it could be proved that the helicities for electron and positron emission are opposite and also the 100% polarisation of internal bremsstrahlung associated with K capture could be measured. For nuclear spectroscopy one can also obtain valuable information on the character of the beta transitions.



Measurement of circular polarisation of gamma rays in beta-gamma coincidence experiments, (H. Schopper, Phil.Mag.2, 710 (1957))
S: beta source, Sc1: scintillator to detect beta particle, Sc2: scintillator to detect gammas, M: magnet with coil C to Compton scatter gammas, Pb: lead absorber to stop direct gammas. Reversing the current in the coil C gives a change in the beta-gamma coincidence rate if the gammas are circularly polarised.

It is somewhat strange that the most obvious consequence of parity violation, the longitudinal polarisation of electrons was not mentioned in the famous paper by Lee and Yang. However, very soon it was predicted by several theorists and finally experimentally demonstrated.

The discovery of parity violation triggered a large number of subsequent experiments and put the theory of the weak interaction on a new basis.

After the first shock of maximal violation of parity and charge conjugation had been digested the next surprise came, the violation of the combined operation CP. In 1964 it was shown that in the decays of the neutral K-particles this operation was also violated, although not maximally like parity but only at the level of about $2x10^{-3}$. Because of the long known CPT theorem, based on very basic principles of field theory and claiming that CPT invariance should be conserved, the question arose whether time reversal invariance was also violated or whether the CPT theorem did not hold. Many experiments were performed to clarify these questions and at CERN even a storage ring, LEAR, and a dedicated experiment on discrete symmetries, CPLEAR, were constructed. So far it seems that T-reversal is violated whereas CPT invariance holds.

All this is now history. What surprises me is that the great shock which parity violation created about 50 years ago has more or less been forgotten, 'verdrängt'. The handedness of particles participating in the electroweak interaction are put into the theory 'by hand', without giving any theoretical arguments. On the other hand the Standard Model SM could easily accommodate P, C and CP violation in its formalism and make very precise predictions for the decays of particles containing heavy quarks.

In 2005 it was discovered that the neutrino masses are not vanishing, a supposition which formed the basis of the two-component neutrino model. With this most recent modification the Standard Model of particle physics seems to be in agreement with all experimental results, even the most recent ones at the LHC. Nevertheless the SM cannot be the final step since it leaves many fundamental questions unanswered. I am convinced the electroweak interaction has more surprises in store for us and a lot of fascinating work remains to be done.

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Histoire de la Physique (9)

Le modèle atomique de Bohr: origines, contexte et postérité (part 2)

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Pour $\tau_2 = 3$, les fréquences correspondent à la série de Paschen (observée en 1908). La formule de Bohr permettait aussi de faire des prédictions: pour $\tau_2 = 1$ la série de Lyman (1913), pour $\tau_2 = 4$ la série de Brackett (1922) et pour $\tau_2 = 5$ la série de Pfund (1924). D'autres observations confirmaient encore toute la force de son modèle. Confronté à l'observation par l'astronome Pickering d'une série de raies de l'hydrogène qui ne coïncidaient pas avec sa théorie, Bohr montrait ainsi brillamment qu'il s'agissait en fait du spectre de l'hélium ionisé.
Sa formule spectrale était donc un succès indéniable. Des étapes de son raisonnement laissaient cependant à désirer, à commencer par la relation (1): il s'agit d'un passage clé mais Bohr n'en donnait, initialement, pas de justification [19]. Certainement, la fréquence de quanta émis dépend de la fréquence de l'orbite de capture, mais c'est tout ce que l'on peut dire. Conscient de cette faiblesse, Bohr retourne sur cette question plus loin dans son article pour proposer une meilleure justification. Il commence par poser

$$-W = f(\tau)h\nu \ ,$$

avec $f(\tau)$ une fonction, à ce stade arbitraire, de τ: L'adéquation avec la série de Balmer impose $f(\tau) = \alpha\tau$ (les fréquences dépendent de l'inverse carré d'un entier), Bohr considère alors le cas limite de deux orbites contiguës de l'atome, caractérisées par une "grande" valeur de τ, $\tau_2 = N\text{-}1$, et $\tau_1 = N$, avec $N >> 1$.
La fréquence du quantum émis lors de la transition est:

$$\nu' = \frac{\pi^2 e^4 m}{2\alpha^2 h^3}\left(\frac{1}{(N-1)^2} - \frac{1}{N^2}\right) = \frac{\pi^2 e^4 m}{2\alpha^2 h^3}\left(\frac{2N-1}{N^2(N-1)^2}\right) \quad (3)$$

alors que les fréquences mécaniques du mouvement qui, d'après l'électrodynamique, sont aussi les fréquences du rayonnement classique sont:

$$\nu_N = \frac{\pi^2 e^4 m}{2\alpha^3 h^3 N^3} \ , \ \nu_{N-1} = \frac{\pi^2 e^4 m}{2\alpha^3 h^3 (N-1)^3} \ .$$

Ces fréquences tendent l'une vers l'autre pour $N \to \infty$. Bohr fait alors remarquer qu'il semble plausible que la fréquence "quantique" de transition, au sens de (3), tende alors aussi vers cette valeur commune: en prenant la limite $N \to \infty$, et en demandant que $\nu' \simeq \nu_N \simeq \nu_{N-1}$ on déduit la valeur $\alpha = ½$. Le même raisonnement (en prenant $\alpha = ½$), appliqué aux orbites $\tau_2 = N\text{-}n$, et $\tau_1 = N$ donne, dans la limite $N \to \infty$:

$$\nu' = \frac{2\pi^2 e^4 m}{h^3}\left(\frac{1}{(N-n)^2} - \frac{1}{N^2}\right) = \frac{2\pi^2 e^4 m}{h^3}\left(\frac{2Nn - n^2}{N^2(N-n)^2}\right) \simeq \frac{4\pi^2 e^4 m}{h^3}\left(\frac{1}{N^3}\right)n$$

alors que les fréquences classiques tendent vers :

$$\nu_N \simeq \nu_{N-n} = \frac{4\pi^2 e^4 m}{h^3 N^3} \ .$$

La fréquence du rayonnement émis lors de la transition coïncide donc, dans cette limite, avec la n-ième harmonique de la fréquence orbitale classique vers laquelle tendent ν_N et $\nu_{N\text{-}n}$: $\nu' \simeq n\nu_N$.

Historiquement, on peut identifier ce raisonnement comme l'embryon du fameux "principe de correspondance" que Bohr utilisera plus tard à maintes reprises dans ses travaux et qui jouera un grand rôle dans la suite de la théorie quantique: on y postule un lien entre le comportement quantique du système et son comportement classique dans la limite $\tau \to \infty$. Le "principe de correspondance", compris ainsi, sera l'un des pilliers de la théorie quantique avant l'avènement de la mécanique quantique. Il faut noter que ce principe, du moins comme l'ont utilisé Bohr et ses disciples, ne correspond pas strictement à ce que nous entendons aujourd'hui par *principe de correspondance*: selon l'acception actuelle, le principe de correspondance permet de retrouver, au niveau formel, la physique classique à partir des expressions quantiques quand on fait tendre la constante de Planck vers 0, $h \to 0$: C'est certainement une manière de caractériser les rapports entre la théorie classique et quantique mais cette interprétation contemporaine ne coïncide pas avec le principe de correspondance tel qu'initié par Bohr qui avait, pendant les années initiales, une signification plus phénoménologique [20].

Malgré la réussite incontestable de son modèle, Bohr n'avait pourtant pas résolu dans son article fondateur le problème de la stabilité de l'atome. A vrai dire il ne le cherchait même pas. De fait, Bohr était convaincu que ce problème ne pouvait pas recevoir de solution dans le cadre de la physique classique et sa démarche l'illustre parfaitement. Fort d'avoir déduit le spectre de Balmer et surtout obtenu l'expression de la constante de Rydberg, Bohr postulait l'existence d'un ensemble dénombrable d'orbites stationnaires sur lesquelles l'électron, malgré son mouvement accéléré, ne rayonnait pas d'énergie: les orbites stationnaires étaient "en quelque sorte des lieux temporaires entre lesquels survient l'émission d'énergie correspondante aux différentes lignes spectrales" [21].

19 On peut cependant considérer la moyenne du mouvement avant la capture (mouvement libre avec $\nu = 0$), et du mouvement circulaire après capture, de fréquence ν. Bien sûr, cette justification est totalement *ad hoc*.

20 Savoir utiliser le principe de correspondance comme le comprenait Bohr exigeait passablement d'intuition dans la situation concrète à laquelle on faisait face. Il n'est pas étonnant qu'en fin de compte ceux qui savaient le manier formaient un cercle dont Bohr était le centre, un cercle où il n'était pas facile d'entrer. Le jeune Louis de Borglie allait l'apprendre à ses dépens dans un de ses premiers travaux, voir J. Lacki, Niels Bohr, article dans le *New Dictionary of Scientific Biography*, Charles Scribner's Sons, 2008.

21 "On the spectrum of hydrogen", in: Niels Bohr, *The theory of Spectra and Atomic Constitution*, Cambridge University Press, 1922, p. 107.

Bohr déclarait, à propos de sa démarche, qu'il la considérait comme "préliminaire et hypothétique". En fait, elle était bien plus radicale: Bohr ne cherchait pas tant à masquer les difficultés de son modèle par ses succès mais, au contraire, il les exacerbait, aspirant ainsi à mettre le plus clairement possible en exergue les contradictions que sa démarche entretenait avec la physique classique. On retrouve là une autre caractéristique de ce que Bohr allait par la suite apporter à la théorie quantique: alors que d'autres (Einstein) refusaient d'abandonner le cadre épistémologique de la physique classique, Bohr, avec son interprétation de la mécanique quantique, devenait le champion de la rupture.

4 Comment généraliser le modèle de Bohr ?

L'approche de Bohr à l'explication du spectre de l'hydrogène fut immédiatement acclamée par la communauté. On se souvient en particulier de la déclaration d'Einstein qui avait salué le travail de Bohr comme "une immense prouesse" [22]. Il est instructif de comparer le modèle de Bohr avec la loi de Planck: dans les deux cas, les résultats ne furent acceptés que grâce à leur portée phénoménologique. La loi de Planck s'imposait par son adéquation avec les mesures du rayonnement de cavité et en aucune manière par son assise "théorique" (la quantification des énergies des résonateurs) dont on s'était, initialement, méfié. De même, la démarche de Bohr trouva grâce aux yeux de ses contemporains par son adéquation à la formule de Rydberg et la théorie des spectres, cela malgré les violations patentes de la physique classique que son modèle impliquait.

Le succès de Bohr appelait à appliquer sa démarche à d'autres atomes (autres que ceux qui pouvaient se ramener au cas de l'hydrogène, comme l'hélium ionisé), mais un problème se posait immédiatement. Le cas considéré par Bohr est trop particulier: son approche repose entièrement sur le fait que la donnée de l'énergie W définit univoquement les caractéristiques de l'orbite (son rayon et sa fréquence). La quantification des valeurs de l'énergie permet de sélectionner ainsi des orbites "permises" dans le continu des configurations classiquement possibles. Dans une situation plus complexe (à commencer par le cas immédiatement suivant des orbites elliptiques) d'autres caractéristiques du mouvement interviennent et les valeurs des paramètres associés ne peuvent être fixées par la seule donnée de l'énergie (il y a dégénérescence).

Il est remarquable que l'article fondateur de Bohr indiquait (certes, *a posteriori*) la voie à suivre. Bohr y remarquait vers la fin qu'il est possible de caractériser les orbites stationnaires d'une autre manière: elles correspondent à une restriction des valeurs du moment cinétique **L**. Dans le type de mouvement considéré par Bohr, l'énergie totale est

$$W = -\frac{e^2}{2r} = -T$$

et comme T = |**L**|$\pi\nu$, quantifier l'énergie revient à quantifier les valeurs du moment cinétique:

$$|\mathbf{L}| = \tau \frac{h}{2\pi} . \qquad (4)$$

22 Voir Max Jammer, *The Conceptual Development of Quantum Mechanics*, McGraw-Hill, 1966, p. 86.

C'était la clé de la généralisation mais il fallait franchir encore quelques étapes. Pour commencer, la quantification du moment cinétique (4) peut reçevoir une expression plus générale: dans les coordonnées polaires φ et r, l'hamiltonien de l'atome (en négligeant le mouvement de son noyau) est:

$$H = T + V = \frac{p_\varphi^2}{2(mr^2)} - \frac{e^2}{r^2} ;$$

La coordonnée φ est cyclique, et ainsi le moment conjugué $p_\varphi = \tau\, h/2\pi$ est une quantité conservée du mouvement. On peut poser, en intégrant sa valeur sur une période du mouvement orbital,

$$\oint p_\varphi d\varphi = p_\varphi \oint d\varphi = \tau \frac{h}{2\pi} 2\pi = \tau h .$$

Il semble donc que la quantification des orbites de Bohr revienne en quelque sorte à quantifier la valeur des intégrales du type

$$\oint p\, dq = \tau h .$$

Que signifient ces intégrales ? Que faut-il faire quand on a plusieurs degrés de liberté ? Ces conditions sont-elles invariantes (conduisent-elles à la même quantification) sous les changement de coordonnées ? Les chemins d'intégration généralisant les orbites circulaires sont-ils clairement définis ? Autant de questions qui seront résolues dans les années qui suivent. L'approche générale qui en ressortira permettra de quantifier une classe générale de systèmes intégrables, les systèmes *multiplement périodiques*. Ce sera l'oeuvre de Bohr, d'Arnold Sommerfeld, et de tous ceux qui, tels Paul Epstein ou Karl Schwarzschild, reconnaîtront l'intérêt d'importer, dans la jeune théorie quantique, les méthodes de la mécanique... céleste.

5 Au-delà de Bohr: quantification de l'espace de phase et invariants adiabatiques

L'application de l'idée de quanta d'énergie à la structure de l'atome par Bohr contredisait aussi bien la mécanique classique que l'électrodynamique. En fait, avant même que Bohr ne remette en cause les deux théories classiques, certains avaient essayé d'obtenir la loi de Planck à partir d'un raisonnement contredisant la physique classique. Dans une communication au congrès Solvay de 1911, Planck, ayant renoncé à l'espoir d'une justification classique à sa loi, posait les premiers pas. Suivant la formulation par Gibbs en 1900 d'une "mécanique statistique" inspirée par les travaux de Boltzmann, la probabilité $P(p; q)$ de trouver un système, décrit par ses coordonnées généralisées q_i et les moments conjugués p_i (i = 1, ..., f parcourt le nombre total de degrés de liberté) dans le volume infinitésimal $dpdq \equiv \prod_{i=1}^{f} dp_i dq_i$ centré sur le point (p, q) de l'espace de phase, est donnée par

$$P(p,q) = \frac{\exp\left(\frac{-H(p,q)}{kT}\right)}{\int dpdq \exp\left(\frac{-H(p,q)}{kT}\right)} dpdq ,$$

où $H(p,q)$ est la valeur de l'hamiltonien H: Pour un oscillateur harmonique unidimensionnel de fréquence propre ν ,

$$H(p,q) = \frac{p^2}{2m} + 2\pi^2\nu^2 mq^2$$

et le calcul de son énergie moyenne donne alors

$$\overline{E} = \int\int dpdqP(p,q)H(p,q) = kT \ .$$

Pour éviter cette conclusion qui mène fatalement à la loi de Rayleigh et sa "catastrophe ultraviolette", Planck montrait qu'en suivant les préceptes de la mécanique statistique on pouvait obtenir l'expression voulue par *sa* loi,

$$\overline{E} = \frac{h\nu}{\exp\left(\frac{h\nu}{kT}\right) - 1} \ ,$$

si l'on faisait l'hypothèse de restreindre les valeurs permises pour l'énergie des oscillateurs aux seuls multiples entiers de la constante h: $E = 0, h\nu, 2h\nu, ..., nh\nu, ...$

$$\overline{E} = \frac{\sum_n nh\nu \exp\left(\frac{-H(p,q)}{kT}\right)}{\sum_n \exp\left(\frac{-H(p,q)}{kT}\right)} = \frac{h\nu}{\exp\left(\frac{h\nu}{kT}\right) - 1} \ .$$

Planck allait, dans ce raisonnement, plus loin que ce qu'il avait avancé lors de la première justification de sa loi en 1900: la quantification de l'énergie de l'oscillateur renvoyait à une raison plus fondamentale, la *quantification* de son espace de phase. En effet, pour une énergie donnée E de l'oscillateur, son mouvement est représenté dans l'espace de phase par une ellipse de demi-axes $a = \sqrt[2]{2E/4\pi^2\nu^2 m}$, $b = \sqrt[2]{2mE}$. La surface de cette ellipse est donnée par:

$$S_E = \pi ab = \sqrt[2]{2E/4\pi^2\nu^2 m}\sqrt[2]{2mE} = \frac{E}{\nu} \ .$$

Ainsi, si on suppose que ces ellipses sont distribuées de manière discontinue, en découpant des surfaces intermédiaires de valeur $S = S_{E_n} - S_{E_{n-1}} = h$, alors les énergies des oscillateurs ne peuvent prendre que les valeurs données par les multiples entiers de $h\nu$. Planck proposait donc de voir la quantification de l'énergie des oscillateurs (unidimensionnels) comme résultant d'un principe plus fondamental, celui d'une discrétisation de l'espace de phase, en "cellules" de taille

$$\int\int_E^{E+\varepsilon} dpdq = h \ .$$

L'existence d'une taille minimale aux cellules de l'espace de phase défiait toute compréhension classique: h a en effet la dimension d'une [action] = [energie] [temps]. Il n'existe cependant aucune loi de conservation de l'action: on ne voyait ainsi pas comment cette discrétisation de cellules pouvait "se maintenir" dans le temps. Cela n'était pas pour décourager Planck qui généralisait en 1915 sa discrétisation de l'espace de phase de l'oscillateur unidimensionnel à des systèmes à f degrés de liberté en considérant des hypersurfaces découpant des portions de l'espace de phase en des éléments de volume $(h)^f$.

Une autre inspiration allait pendant ce temps compléter les spéculations de Planck. Peu de temps après Bohr et son article fondateur, Sommerfeld suggérait comment il fallait le généraliser. Le Danois avait, comme on l'a vu, remarqué que la condition définissant les orbites permises (états stationnaires) était équivalente à la quantification du moment cinétique en unités de $h/2\pi$:

$$|\mathbf{L}| = \tau\frac{h}{2\pi} \ .$$

Sommerfeld reprenait cette condition en termes de l'intégrale (prise sur une orbite) déjà vue:

$$\oint p_\varphi d\varphi = \tau h$$

où le moment p_φ est conjugué à la coordonnée angulaire φ paramétrant la trajectoire de l'orbite. Participant tout comme Planck au premier congrès Solvay [23] , Sommerfeld connaissait bien les réflexions de Planck sur les cellules élémentaires de l'espace de phase. Dans les coordonnées canoniques φ et p_φ les mouvements permis correspondent aux segments droits données par $p_\varphi = \tau\, h/2\pi$, φ variant entre $-\pi$ et π, et on peut reprendre tout le raisonnement de Planck pour retrouver ainsi le résultat de Bohr. Sommerfeld en venait à penser que la quantification des orbites de Bohr avait pour justification plus fondamentale la quantification des valeurs des intégrales de la forme:

$$\oint p\, dq = \tau h \ .$$

Il proposa fort logiquement de généraliser la démarche de Bohr, pour un nombre de degrés de liberté f, par la considération de f conditions de quantification (les p_i sont conjugués aux q_i):

$$\oint p_i dq_i = \tau_i h \ , \quad i = 1, ..., f \quad (5)$$

Des propositions similaires étaient à l'époque avancées par Wilson et Ishiwara [24], mais l'affaire était loin d'être aussi simple. Il fallait encore savoir sur quel contour il convenait d'intégrer [25] et par ailleurs il n'était pas sûr que les f conditions étaient *toutes* réellement pertinentes. C'est ce que Sommerfeld apprit à ses dépens en essayant de généraliser les orbites de Bohr à des ellipses dans l'espoir d'expliquer la structure fine du spectre de l'hydrogène. Dès 1891 on sa-

23 Il y avait fait une contribution importante en essayant de rattacher les discontinuités quantiques à un principe plus fondamental et plus général, celui de la quantification de l'intégrale d'action de Hamilton, $S = \int Ldt$. Sa démarche s'inscrivait bien dans la direction que prenait alors la physique quantique: il ne s'agissait plus de dériver l'existence du quantum d'action h d'une physique classique mais de prendre acte de sa fondamentale importance et de repenser en conséquence les principes mécaniques et électrodynamiques de la physique. C'est exactement ce qui fit également Bohr.

24 W. Wilson, The quantum theory of radiation and line spectra, *Philosophical Magazine*, vol. 29 (1915), 795-802 ; J. Ishiwara, Die universelle Bedeutung des Wirkungsquantums, *Tokyo Sugaku Buturigakkawi Kizi*, vol. 8 (1915), 106-116. Les deux démarches se proposaient de parvenir à un traitement unifié de la quantification du résonateur de Planck et de l'atome de Bohr. Pour plus d'informations voir M. Jammer, *op. cit.*, p.91-93.

25 La question revêtait toute son importance surtout dans le cas de trajectoires non-fermées, ainsi les orbites paraboliques et hyperboliques du problème de Kepler. Le cas des orbites circulaires ou elliptiques de ce problème, ainsi que le cas de l'oscillateur harmonique présentaient une évidente périodicité qui fournissait la réponse.

vait, grâce aux observations de Michelson [26], que le spectre de Balmer n'était pas constitué de lignes simples, mais de doublets [27]. Sommerfeld espérait arriver à expliquer cette "structure fine" de la série de Balmer en termes de transitions entre des états stationnaires supplémentaires. En travaillant avec deux conditions pour l'angle φ et le rayon r et en introduisant deux nombres quantiques [28] k et n':

$$\oint p_\varphi d\varphi = kh\ , \quad \oint p_r dr = n'h\ ,$$

Sommerfeld obtenait pour les valeurs de l'énergie:

$$W = -\frac{2\pi^2 e^4 m}{h^2}\frac{1}{(k+n')^2}\ .$$

Comme on le voit par comparaison avec (2), Sommerfeld n'obtenait rien de plus que ce qui était déjà prédit avec les orbites circulaires de Bohr. Bien sûr, ses orbites étaient plus générales que celles de Bohr (elles décrivaient des ellipses avec comme rapport du petit au grand demi-axes $\frac{b}{a} = \frac{k}{k+n'}$), mais leurs énergies étaient dégénérées: elles ne dépendaient que de la somme des nombres quantiques $k + n'$: Nullement découragé par ce résultat, Sommerfeld passait à un traitement dans les trois dimensions de l'espace, avec une quantification du plan des orbites, en imposant (dans les coordonnées polaires) les conditions de quantification:

$$\oint p_\varphi d\varphi = n_1 h\ , \quad \oint p_r dr = n'h\ , \quad \oint p_\theta d\theta = n_2 h\ ,$$

mais il n'obtenait, encore une fois, que les mêmes énergies que Bohr, avec encore une plus grande dégénérescence.

Ce n'est que quand Sommerfeld décida de traiter le problème en tenant compte de la relativité qu'il réussit à lever la dégénérescence des énergies avec, comme expression pour celles-ci, à l'ordre carré de la constante de la structure fine $\alpha \equiv \frac{2\pi e^2}{hc}$,

$$W = \frac{-2\pi^2 e^4 m}{h^2}\left[\frac{1}{(k+n')^2} + \frac{\alpha^2}{(k+n')^4}\left(\frac{n}{k} - \frac{3}{4}\right)\right].$$

Le traitement relativiste de Sommereld apportait une réponse remarquable au problème de la structure fine. Les errements de sa démarche illustraient cependant que l'on ignorait encore ce que devaient être précisement les règles de quantification: la prescription (5) ne devait manifestement pas être toujours appliquée telle quelle, des conditions supplémentaires pouvaient intervenir. Deux développements allaient apporter des réponses décisives: ils convergèrent rapidement vers un aperçu unique aux assises formelles bien précises.

Le premier développement interrogeait la signification des conditions de quantification. On allait comprendre que la forme de ces conditions n'était pas arbitraire et renvoyait à un principe plus profond. C'était, suite aux travaux pionniers de Boltzmann, Clausius, Helmholtz et Hertz, et l'apport décisif, au XXe siècle de Rayleigh et surtout d'Ehrenfest, la reconnaissance du "principe adiabatique" [29]. Les origines de ce principe remontent à l'étude des liens entre le second principe de la thermodynamique et les lois de la mécanique [30]. Boltzmann considérait dans ce contexte le problème de savoir comment, pour un système obéissant au principe de moindre action et suivant une trajectoire périodique de période $\tau = 1/\nu$, une variation de son énergie cinétique dE se répercutait sur les détails de son mouvement. Il identifiait ainsi, pour la condition $dE = 0$, un "invariant adiabatique" donné par le rapport $\frac{\overline{E}_{cin}}{\nu}$. Ce cours d'idées allait culminer, un demi-siècle plus tard, avec Paul Ehrenfest qui, en définissant le cadre général des transformations "adiabatiques", permettait de saisir la signification des conditions de quantification de Bohr-Sommerfeld. L'année même du modèle de Bohr, Ehrenfest, ayant pris la succession de Lorentz à Leyde, expliquait que, pour un système décrit par des coordonnées généralisées q_1, q_2, ..., q_f dépendantes d'un certain nombre de paramètres a_1, a_2, ... qui peuvent varier (infiniment) lentement, on pouvait considérer des transformations "adiabatiques" qui relient un mouvement paramétrisé par les valeurs a_1, a_2, ... à un autre paramétrisé par a'_1, a'_2, ... Ehrenfest établissait alors que, pour un mouvement "permis" (stationnaire au sens de Bohr), caractérisé par des a_1, a_2, ... les seuls autres mouvements permis étaient liés au mouvement initial par des transformations adiabatiques [31]. Avec son principe adiabatique, Ehrenfest faisait d'une observation deux coups: il justifiait la possibilité d'imposer des conditions de quantification à des situations classiques caractérisées par des paramètres variant lentement dans le temps, mais il indiquait aussi (et surtout) la voie vers la quantification de système arbitraires pourvu que leurs mouvements puissent être liés, adiabatiquement, à des mouvements de systèmes aux conditions de quantification connues. De fait, les intégrales de Bohr-Sommerfeld (5), identifiées comme des invariants adiabatiques [32], expliquaient le sens des conditions de quantification.

Il fallut encore une autre avancée pour éclairer d'avantage le sens théorique des procédures de quantification et pour

26 A. A. Michelson, On the application of interference-methods to spectroscopic measurements, *Philosophical Magazine*, vol. 31 (1891), 338-346, aussi vol. 34 (1892), 280-299.

27 Il est à ce propos remarquable que la structure en doublet du spectre n'ait pas empêché l'accceptation des conclusions de Bohr: techniquement parlant, le modèle de Bohr était falsifié par cette "structure fine" du spectre. Ce n'est cependant pas la première fois où une découverte était acceptée alors qu'elle était, platement, réfutée par les données expérimentales: l'histoire et la philosophie des sciences en ont pris toute la mesure dans leurs critiques de la philosophie de la réfutation prônée par Popper.

28 Le terme de "nombre quantique" provient de fait de Sommerfeld: dans son article fondateur Bohr ne faisait encore référence qu'à des "entiers".

29 Voir Max Jammer, *op. cit.*, p. 97-101.

30 L. Boltzmann, Ueber die mechanische Bedeutung der zweiten Hauptsatzes der Wärmetheorie, *Wiener Berichte*, vol. 53 (1866), 195-220 ; R. Clausius, Ueber die Zurückführung des zweiten Hauptsatzes der mechanischen Wärmetheorie auf allgemeine mechanistische Principien, Poggendorf's *Annalen der Physik*, vol. 142 (1871) 433-461.

31 P. Ehrenfest, Adiabatische Invarianten und Quantentheorie, *Annalen der Physik*, vol. 51 (1916), 327-352 ; aussi *Collected Scientific Papers*, M. J. Klein (ed.), North-Holland, 1959, p 378-399.

32 Adiabatische Invarianten und Quantentheorie, *op. cit.*, p. 338. En particulier on constate facilement que la quantification initiale du moment cinétique par Bohr est celle d'un invariant adiabatique puisque

$$\oint p_\varphi d\varphi = 2\pi m v r = 2\frac{\overline{E}_{cin}}{\nu}\ .$$

les rendre applicables plus largement. La solution allait passer par un savoir dont les physiciens jusque là, n'étaient pas familiers.

6 Au-delà de Bohr: systèmes multiplement périodiques, mécanique céleste et atomes

L'autre front sur lequel s'est joué le progrès des idées initiées par Bohr concernait la question de l'expression formelle des intégrales (5). Les démarches infructueuses de Sommerfeld indiquaient, comme on l'a vu, que le nombre des conditions de quantification pouvait être inférieur au nombre de degrés de liberté. Par ailleurs, il restait aussi la question des contours sur lesquels il fallait calculer ces intégrales, question qui renvoyait à celle, plus délicate et profonde, du choix des coordonnées dans lesquelles il fallait imposer ces conditions. Les réponses furent obtenues dans le cadre d'un approfondissement de la question en termes de la mécanique analytique de Lagrange et de Hamilton. Les physiciens de l'époque n'en étaient pas familiers: l'étude des techniques avancées de la mécanique analytique était alors plus l'apanage des astronomes et des mathématiciens [33]. Ces techniques s'avérèrent pourtant cruciales pour parvenir à une compréhension approfondie des principes de quantification initiés par Bohr et généralisés par Sommerfeld. L'observation essentielle était le rôle joué par une classe distinguée de systèmes exactement intégrables, ceux pour lesquels l'équation de "Hamilton-Jacobi" pouvait être résolue par séparation. L'histoire commence au XIXe siècle avec Carl Jacobi et son étude du problème de Kepler: il montra que l'équation à laquelle il associe aujourd'hui son nom pouvait être dans ce cas "séparée" [34]. L'étude des conditions assurant l'existence de telles coordonnées séparatrices et de leur unicité avait depuis occupé nombre des travaux de mathématique et de mécanique rationnelle. On allait montrer ainsi que les systèmes dont la dynamique pouvait être résolue par séparation de variables étaient "multiplement périodiques": la réalité de leur mouvement (rendue explicite dans les coordonnées appropriées) était celle d'une superposition de mouvements périodiques en analogie avec les figures de Lissajous [35]. Les coordonnées séparatrices permettaient de définir à leur tour un nouveau jeu de coordonnées, connues, depuis des décennies, en astronomie, mais dont l'utilité allait maintenant se révéler aussi aux physiciens de l'atome, les coordonnées *action-angle*. Permettant, en mécanique céleste, un calcul aisé des périodes de révolution, les coordonnées action-angle allaient s'avérer aussi de première importance pour la théorie de la quantification: les travaux de Paul Epstein et de Karl Schwarzschild faisaient comprendre que les intégrales de Sommerfeld (5), calculées sur une période du mouvement sous-jacent, correspondaient précisement aux valeurs (conservées) des variables d'action associées [36]: dans les variables action-angle l'Hamiltonien du système ne dépend pas des variables d'angle (celles-ci sont toutes cycliques), mais que des variables d'action dont la quantification est, par conservation, préservée dans le temps. La théorie des systèmes multiplement périodiques permettait aussi de répondre à la question du nombre de conditions de quantification que l'on devait imposer: tout dépendait de la possible commensurabilité des fréquences des mouvements périodiques sous-jacents: en cas des périodes commensurables, il y avait dégénérescence et le nombre de variables d'action indépendantes était alors inférieur au nombre des degrés de liberté.

L'apport des techniques de la mécanique céleste et en particulier du formalisme des variables action-angle fut déterminant: l'analogie de l'atome comme un micro-système planétaire allait être plus qu'une métaphore: elle allait permettre de donner un cadre précis à la quantification de systèmes plus généraux que l'atome d'hydrogène. Les résultats de Schwarzschild et Epstein furent rapidement généralisés par Bohr, Born etc. en un formalisme aux règles sûres [37]: les travaux, qui, sur une dizaine d'années, séparent le modèle atomique de Bohr de la mécanique matricielle de Heisenberg allaient en être entièrement tributaires. Face à une situation atomique, le physicien quantique l'approximait (au sens de la théorie des perturbations) par un système multiplement périodique qui lui permettait de poser la quantification des variables d'action associées. Il déduisait l'information sur les fréquences des raies spectrales et leurs intensités (relatives) en étudiant le développement en série multiple de Fourier réflétant les périodicités sous-jacentes: pour toute grandeur physique *O* d'un tel système, son évolution dans le temps *t* est donnée par l'expression:

$$O(t) = \sum_{n_1, n_2, \ldots, n_g = -\infty}^{\infty} O_{n_1, n_2, \ldots, n_g}(J_1, J_2, \ldots, J_g) \cdot \exp 2\pi i (\nu_1 n_1 + \nu_2 n_2 + \ldots + \nu_g n_g) t \,. \tag{6}$$

Dans la formule ci-dessus le nombre de couples de variables action-angle, g, n'égale pas nécessairement, on le sait déjà, le nombre de degrés de liberté f du système: il peut y avoir dégénérescence, auquel cas $g < f$: c'est ce qui se passe dans le problème de Kepler traité par Sommerfeld. Les coefficients de Fourier $O_{n_1, n_2, \ldots, n_g}$, fonctions des variables quantifiées d'action $J_1 = \tau_1 h$, $J_2 = \tau_2 h$, ... , $J_g = \tau_g h$, paramétrant les orbites stationnaires, permettent de déduire les intensités des raies alors que l'information sur leurs fréquences exige

33 Tout cela a à faire avec l'émergence à cette époque d'une nouvelle figure, celle du physicien théoricien, conquérant son autonomie par rapport aux préoccupations expérimentales de ses collègues, et prenant possession, au nom de sa démarche propre, de ce qui était encore dévolu à la physique mathématique, aux mathématiques, et à l'astronomie. Voir à ce sujet l'ouvrage incontournable de Christa Jungnickel and Russel McCormach, *Intellectual Mastery of Nature: Theoretical Physics from Ohm to Einstein*, vol. I : *The Torch of Mathematics, 1800-1870*, University of Chicago Press, 1990.

34 C. G. Jacobi, *Vorlesungen über Dynamik*, Reimer, 1866, pp. 183-198. Pour un traitement moderne, voir par exemple H. Goldstein, *Classical mechanics*, Addison-Wesley, 1950, ou, pour plus de détails et un traitement plus mathématique, H. Rund, *The Hamilton-Jacobi theory in the calculus of variations*, Van Nostrand, 1966.

35 O. Staude, Ueber eine Gattung doppelt reell periodischer Funktionen zweier Veränderlicher, *Mathematische Annalen*, vol. 29 (1887), 468-485; P. Stäckel, Ueber die Integration der Hamilton-Jacobischen Differentialgleichung mittels der Separation der Variablen, *Mathematische Annalen*, vol. 42 (1893), 545-563, et références y contenues. Voir aussi M. Jammer, *op. cit*, p. 102.

36 K. Schwarzschild, Zur Quantenhypothese, *Berliner Berichte*, 1916, 548-568 ; P. S. Epstein, Zur Theorie ds Starkeffektes, *Annalen der Physik*, vol. 50 (1916), 489-520 ; Zur Quantentheorie, *Annalen der Physik*, vol. 51 (1916), 168-188.

37 N. Bohr, On the application of the Quantum Theory to atomic structure, *Proceedings of the Cambridge Philosophical Society* (supp.), 1924 ; M. Born, *Vorlesungen über Atommechanik*, Berlin: Springer, 1925.

de faire usage du principe de correspondance [38]. Ce formalisme, directement issu de la généralisation du modèle de Bohr et que nous dirions aujourd'hui (au mieux) "semi-classique", allait faire l'affaire pendant une dizaine d'années: les historiens de la physique le taxent de "vieille théorie quantique" pour souligner son caractère provisoire avant que ne fut établie la mécanique quantique. Son intérêt historique, malgré sa nature éphémère, est considérable: Heisenberg s'appuya directement sur son contenu formel pour poser les bases de la mécanique matricielle (première forme de la mécanique quantique). La "vieille théorie quantique" fut ainsi une étape essentielle sur le chemin de la formulation de la mécanique quantique: pour comprendre pourquoi, il suffit de se pencher sur la structure des termes de la série (6): les coefficients de Fourier $O_{n_1, n_2, \ldots, n_g}$ renvoient à deux jeux d'entiers, le premier donnant les valeurs des variables d'action de l'orbite stationnaire sous examen, $J_i = \tau_i h$, le second (les n_i) indiquant l'ordre harmonique (multiple) du terme considéré. On le voit, ces coefficients de Fourier peuvent être rassemblés en un tableau de nombres: après un changement adéquat d'indices de sommation les deux jeux d'entiers peuvent être vus (lignes et colonnes) comme paramétrant des paires d'états stationnaires discrets, plus précisement comme référant aux processus de transition entre de tels états [39]. Ce sont, de fait, les tableaux des nombres dont Heisenberg, grand expert de la "vieille théorie quantique" fera, en été 1925, la base d'un nouveau formalisme, celui d'une mécanique matricielle. Quelques mois plus tard Schrödinger proposait sa mécanique ondulatoire; à peine une année plus tard la synthèse de la mécanique matricielle et de la mécanique ondulatoire débouchait sur la "théorie des transformations" de Jordan et Dirac dont Johann (bientôt John) von Neumann allait préciser le cadre mathématique (la théorie de l'espace de Hilbert) [40]. "Notre" mécanique quantique était née.

38 Le principe de correspondance permettait de relier, dans l'expression (6), l'exposant de l'exponentielle fait d'une somme linéaire d'harmoniques des fréquences fondamentales $\nu_i = \partial H/\partial J_i$ aux fréquences de transition quantiques, $\nu(n; m) = (E(n)-E(m))/h$ entre deux niveaux stationnaires d'énergie E(n), E(m) ; pour plus de détails, voir Jan Lacki, From matrices to Hilbert spaces: the quest of the final formalism, in *The Discovery of Quantum Mechanics*, H.-Ch. Dehne, G. Drews, H. Mais , H. Rechenberg (éds), Hamburg : proceedings DESY, 2000, p. 41-92 ; Early Axiomatizations of Quantum Mechanics : Jordan, von Neumann and the continuation of Hilbert's program, *Archive for the History of Exact Sciences*, vol. 54 (2000), p. 279-318 ; Observability, Anschaulichkeit and Abstraction. A journey into Werner Heisenberg's science and philosophy, in *100 Years Werner Heisenberg - Works and Impact*, A. von Humboldt Foundation, numéro spécial de *Fortschritte der Physik*, Luest, D. et al. (éds), vol. 50 (2002), No 5-7, p. 440-458.

39 Il faut à ce stade faire usage du principe de correspondance, voir les références de la note précédente.

40 Voir les références citées dans les notes plus haut.

Jost Bürgi, Kepler und der Kaiser

Buchbesprechung von Bernhard Braunecker

Wer selbst nicht mehr mit Logarithmen und Rechenschieber gerechnet hat, kennt ihn wahrscheinlich nicht. Wer sich nicht intensiv mit Johannes Keplers Neuer Astronomie am Kaiserhof in Prag auseinander gesetzt hat, dem ist er kaum ein Begriff. Und wer sich nicht so sehr für Himmelsgloben und Renaissanceuhren interessiert, hat wahrscheinlich nie von ihm gehört: dem Universalgenie Jost Bürgi (1552–1632). Wer allerdings unsere SPG-Mitteilungen regelmässig liest und wer auf unserer SPG-Homepage schon einmal unter der Rubrik "Anekdoten" gesurft ist, der weiss, dass dieser Toggenburger es war, der die Frühe Neuzeit zum Ticken brachte. *Fritz Staudacher*, der Autor unserer Beiträge über Jost Bürgi, hat soeben im Verlag NZZ Libro ein Buch veröffentlicht, das all diese Facetten Jost Bürgis erstmals gleichzeitig zum Glänzen bringt: den Instrumentenbauer (Proportionalzirkel, Triangulationsgerät, Metallsextant) ebenso wie den Uhrenkonstrukteur (erste Sekundenuhr, kleinster und präzisester Himmelsglobus) sowie den gewieften Mathematiker (Prosthaphärese, Logarithmen, algebraische Geometrie) und den unermüdlichen Himmelsbeobachter Jost Bürgi, von dem Johannes Kepler in einem bis anhin nicht bekannten Ausmass profitierte.

Frontispiz zu Bürgis Bedienungsanleitung für sein Triangulationsinstrument. Kupferstichporträt von Ägidius Sadeler, Illustrationen von Anton Eisenhoit.

Der Autor stellt Jost Bürgi in seine Zeit und beschreibt die damals wichtigen Parameter der politischen, kulturellen und wissenschaftlichen Situation im Vorfeld des Dreissigjährigen Krieges. Als dieser 1618 mit dem zweiten Fenstersturz in Prag auf dem Hradschin beginnt, erfolgt dies in unmittelbarer Nähe zu Bürgis Werkstatt. Indem er in Prag von 1603 bis 1630 drei Kaisern als Kammeruhrmacher dient und im selben Haus wie der alchemistenfreundliche Kaiser Rudolf II. und der Bildhauer Adriaen de Vries seine Werkstatt hat, lebt und arbeitet er als Schweizer im Machtzentrum des Heiligen Römischen Reiches Deutscher Nation. So bietet diese erste umfassende Biographie Jost Bürgis eine Vielfalt an Informationen aus der Frühen Neuzeit, illustriert mit 245 ausgezeichneten Bildern. Wer für sich für die Technik-, Mathematik- und Astronomie-Geschichte interessiert, findet hier eine Vielfalt an Beispielen. Und wer gleichzeitig ein schönes Weihnachtsgeschenk sucht, kommt hier in den Genuss eines graphisch beeindruckenden Prachtbandes.

Jost Bürgis einzigartige Wiener Bergkristalluhr, gefertigt von ihm 1622/27 in seiner Werkstatt auf dem Hradschin in Prag. Ausgestattet mit Sekundenanzeige, Mondzifferblatt, Miniaturglobus und Kreuzschlaghemmung.

Staudacher Fritz: Jost Bürgi, Kepler und der Kaiser. Uhrmacher, Instrumentenbauer, Astronom und Mathematiker (1552–1632). 293 Seiten, 245 Abbildungen. Verlag Neue Zürcher Zeitung. ISBN 978-3-03823-828-7.

Tres faciunt collegium:
Kepler, Brahe und Jost Bürgi.

In dieser Biografie Jost Bürgis schildert Staudacher auch die Zusammenarbeit der drei Astronomen Johannes Kepler, Tycho Brahe und Jost Bürgi, die sich zum richtigen Zeitpunkt am richtigen Ort trafen: Kepler, der Visionär, Theoretiker, Vordenker; Brahe, der Experimentator, Organisator, Geldbeschaffer, und Bürgi, der Entwickler neuartiger Präzisionsinstrumente und praxisgerechter Rechenalgorithmen. Ihrem historischen Zusammentreffen im Jahre 1600 in Prag ist zu verdanken, dass Kepler seine Theorie mittels Bürgischer Rechenmethoden in effizienter Weise an Tychos umfangreicher, sich über mehrere Dekaden erstreckender Datensammlung verifizieren konnte. Dabei waren die Voraussetzungen gar nicht so günstig, denn "Johannes Kepler sieht schlecht, Tycho Brahe rechnet nicht gerne, Jost Bürgi fällt das Schreiben schwer".
Da aber "Kepler ein aussergewöhnlicher Mathematiker, Brahe ein unermüdlicher Himmelsbeobachter und Bürgi ein alle mathematisch-technischen Funktionen integrierendes Universalgenie" ist, revolutioniert dieses europäische Dreigestirn eines deutschen Mathematikers, eines dänischen Astronomen und eines schweizerischen Uhrenmachers die Kenntnisse über unsere Welt.

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- Le prix SSP offert par l'entreprise IBM pour un travail de recherche d'une qualité exceptionnelle en physique de la matière condensée
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- Le prix SSP offert par le METAS pour un travail de recherche d'une qualité exceptionnelle faisant référence au domaine de la métrologie

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: 31. Januar 2014

Délai: 31 janvier 2014

Die Preise werden an der Jahrestagung 2014 in Fribourg überreicht.

Das Preisreglement befindet sich auf den Webseiten der SPG: www.sps.ch

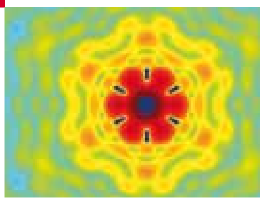
Les prix seront attribués à la réunion annuelle qui se tiendra en 2014 à Fribourg.

Le règlement des prix se trouve sur les pages Web de la SSP: www.sps.ch

Annual Congress 2013 of the Swiss Academy of Sciences (SCNAT)

The Quantum Atom at 100 – Niels Bohr's Legacy

November 21-22, 2013 | Winterthur



The congress will celebrate the 100th anniversary of Niels Bohr's publication „On the Constitution of Atoms and Molecules" and offer an overview on subsequent developments, leading to the modern version of quantum mechanics and its implications and to the current understanding of the constitution of matter.
The Zurich University of Applied Science in Winterthur will host this year's congress.

- **Aspects of Bohr's 1913 Atomic Theory:** **Helge Kragh,** University of Aarhus, Denmark
- **From Bohr's Atom to Quantum Mechanics:** **Olivier Darrigol,** CRNS, Paris
- **Ultrahigh-Resolution Spectroscopy of the Hydrogen Atom:** **Thomas Udem,** MPI Quantum Optics, Garching
- **Muonic Hydrogen: Atomic Physics for Nuclear Structure:** **Randolf Pohl,** MPI Quantum Optics, Garching
- **Antihydrogen: Past, Present, Future:** **Michael Doser,** CERN, Geneva
- **Hydrogen, the Most Abundant Element in the Universe:** **Ruth Durrer,** University of Geneva
- **Defining and Measuring Time: From Cesium to Atomic Clocks: Jacques Vanier,** University of Montreal, Canada
- **Rydberg States of Atoms and Molecules:** **Frédéric Merkt,** ETH Zurich
- **Manipulating trapped Photons and raising Schrödinger Cats of Light:** **Serge Haroche,** Nobel Laureate 2012, ENS and Collège de France, Paris
- **At the End of the Periodic Table:** **Yuri Oganessian,** JINR, FLNR, Dubna, Russia
- **Insights and Puzzles in Particle Physics:** **Heinrich Leutwyler,** University of Bern
- **Quantum Mechanics and Photosynthesis:** **Rienk van Grondelle,** VU Amsterdam, The Netherlands

Public Evening Lecture: **Reinhard Werner,** Leibniz Universität Hannover:
Die **Bohr-Einstein-Debatte zur Quantenmechanik**

There is no conference fee for registered participants. Registration Deadline: November 1st, 2013
More information and registration: http://congress13.scnat.ch

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Swiss Academy of Sciences
Akademie der Naturwissenschaften
Accademia di scienze naturali
Académie des sciences naturelles