europhysicsnews

42/1
2011

Interview with Michael E. Fisher
The laser, from yesterday to tomorrow
Amazing candle flames
The discovery of superconductivity
Water in space

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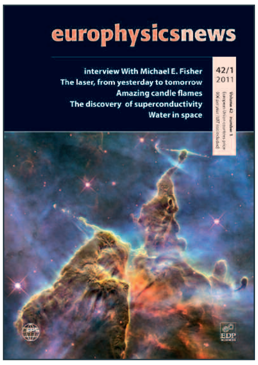
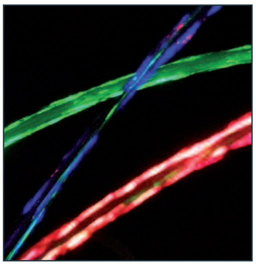


europhysicsnews

Cover picture: Image taken by the Hubble Space Telescope of a small portion of one of the largest star-birth regions in the galaxy, the Carina Nebula. This optical image captures the top of a pillar of gas and dust (about three light years in size) that is being eaten away by the brilliant light from nearby bright stars.



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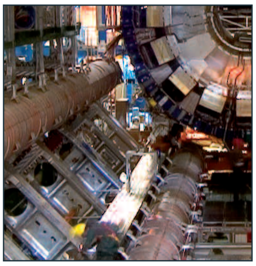
The laser, from yesterday to tomorrow



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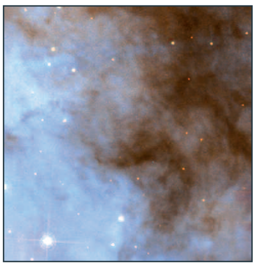
The discovery of superconductivity



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Water in space

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Editor
Claude Sébenne (FR)
Email: claude.sebenne@impmc.upmc.fr

Science Editor
L.J.F. (Jo) Hermans (NL)
Email: Hermans@Physics.LeidenUniv.nl

Executive Editor
David Lee
Email: d.lee@eps.org

Graphic designer
Xavier de Araujo
Email: x.dearaujo@eps.org

Director of Publication
Jean-Marc Quilbé

EPS Secretariat
address: EPS • 6 rue des Frères Lumière
68200 Mulhouse • France
tel: +33 389 32 94 40 • **fax:** +33 389 32 94 49
web: www.eps.org

Secretariat is open 09.00–12.00 / 13.30–17.30 CET except weekends and French public holidays.

EDP Sciences
Managing Director: Jean-Marc Quilbé

Production: Agnès Henri
Email: henri@edpsciences.org

Advertising: Jessica Ekon
Email: jessica.ekon@edpsciences.org

address: EDP Sciences
17 avenue du Hoggar • BP 112 • PA de Courtabœuf
F-91944 Les Ulis Cedex A • France
tel: +33 169 18 75 75 • **fax:** +33 169 28 84 91
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Entering a **new decade**

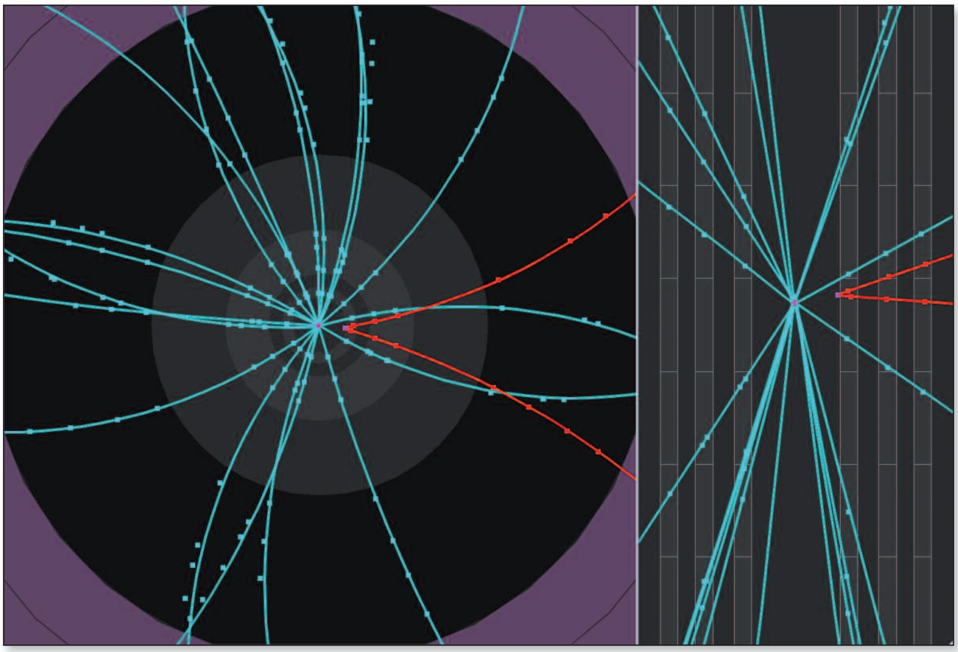
As always, entering a new decade is the occasion to raise questions concerning the future. The questions concern not only the future of the EPS – this has been dealt with by the Strategy Working group during several months – but also the future of science in general and physics in particular. Researchers working at the biggest experiments conducted in CERN answer "the future is exciting and full of new data, it may even be conducting to new theories and (who knows?) to the Unified Theory of Everything – at least, to the Higgs boson – or to New Physics, understanding of gravity, black matter and black energy." It should at least bring more exciting details about the Standard Model. Those dealing with solid state and soft-matter physics create and explore the nano-world. Physicists involved in biology and medicine contribute to make dreams become true through time-resolved observations on the molecular scale, which allow to understand and then cure living bodies. Therefore one expects breakthroughs in many domains of physics. Why? What is different now, compared to a new decade, 30 years ago?
During the last three decades, we lived a kind of revolution. Until then (~1980) we used to teach students, not only (say) physics but the methods of conducting research: both experimental and theoretical. With the new century, a new element appeared: students, as our children (and grand children) started to be smarter than their professors in using the more and more powerful universal tool, the Computer. It has started an era in which getting knowledge and information is the easiest thing to everybody. Without computers, not only contemporary science could not exist, but also the whole World would collapse. This new ability to deal quickly with huge numbers of data has created a new world, not only in physics but everywhere (financial operations, stock exchange, meteorology, image processing…). One expects new science and new physics to be seen soon, new science based on the recognition of similarities, analysis of very big amounts of data, analysis of high order correlations and the possibility of ab-initio modeling of everything. These possibilities change our approach in physics, from the analysis of the former "ideal isolated system" to global Truth of complex correlations in complex and enormously big banks of data, *i.e.* the Reality.
Physics has begun to be the transformation of information rather than the pure speculative domain based on the "Gedankenexperiment" (thought experiment) picture of Reality.
To such physics we need specialists of data-transforming, working effectively on big banks of information and cooperating effectively (using modern cooperation tools) with the best motivated of the young generation. They start training in this field from kindergartens and, through computer games, they come to a different look at the world, maybe virtual from our point of view. They are able to quickly find the information they need and transform it properly, in the analysis of pictures and texts banks, just for simple use or for finding simplicity or symmetry, for example.
Of course this is nothing new – physics always progressed through young persons solving problems before they learned that it was not possible to solve them – but this time the transformation seems to be deeper.
Asking the youngest students whether they like science and technology? The answer is NO. But it does not mean that they are not interested in investigations and creation of knowledge. Then, the question is not the right one. One should ask about their interest in information treatment, computer modeling and informatics, and of course, about the creative and innovative aspects of their future occupation - with a lot of imagination and computer work to be successful.
This is the future of science, in this field youngsters are the best and I hope they will like this kind of activity: New Physics. ■

Maciej Kolwas, President of the EPS

Learning with the ATLAS Experiment in CERN

Introduction

In 2009 the new collider at CERN started to produce long awaited particle collisions in large numbers. The ATLAS Experiment (http://atlas.ch/) was one of the huge particle physics experiments at the Large Hadron Collider that registered particle collisions deep underground at the 27 km accelerator ring. The main aim of the ATLAS detector is to search for new discoveries in the head-on collisions of protons of extraordinarily high energy and learn about the basic forces that have shaped our Universe. The particle collisions in the ATLAS experiment can also be explored by students at school. The *Learning with ATLAS@CERN* education project, described below by Lazoudis and Sotoriou, has developed education scenarios for schools and Science Centres using both simulated and real particle collision data. ATLAS has for long involved students and teachers at many levels – from high school to university. With the Learning with ATLAS education project, ATLAS continues to reach out to schools and universities. The ATLAS experiment is huge, about 45 m long, and more than 25 m high and wide. ATLAS weighs about 7000 tons, about the same as the Eiffel Tower and is about half as big as the Notre Dame Cathedral in Paris.



▲ FIG. 1: A K^0 particle decaying in the inner detector of ATLAS.

An event display of a typical particle collision in ATLAS can be seen in Fig. 1. Particle collisions like this have been used in student events in several European countries, like Greece, UK and Sweden. Fig. 2 shows students in Stockholm studying strange particles produced in particle collisions from the first data-taking run at CERN. They succeed to identify the decaying strange particle, the K^0 particle, by observing the decay point in the inner detector of ATLAS. They also succeed to determine its mass and estimate its lifetime. The K^0 particle is well known, but sometimes the students have to be prepared for the unknown, which is also true for the ATLAS physicists (Fig. 3).

K. Erik Johansson,
Fysikum, Stockholm University, Sweden

Presentation: The case of Learning with ATLAS @ CERN project[1]

Nature *has the ability to throw us the biggest surprises, so expect dramatic twists and unexpected turns; many before you have dreamed up mind-blowing theories and crazy concepts. Some of these have prevailed against the tests of time and armies of knowledgeable critics – thus far. Someone, sometime, somewhere, may succeed in completing these unfinished mysteries, or even rewrite the chapters entirely. The book is by no means finished. CERN Subatomic Venture (http://public.web.cern.ch/Public/)*

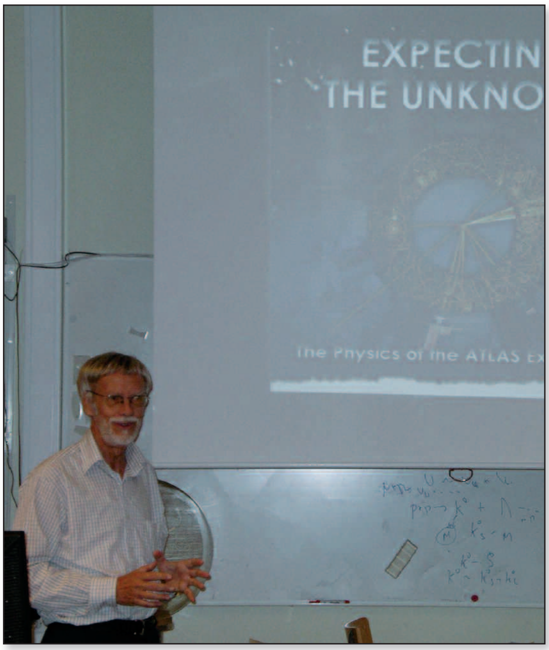
Originally developed at CERN as a tool to help scientists share information, the World Wide Web continues to be an important mode of communication for scientific inquiry. Rich science databases in a variety of fields are publicly available, and

▼ FIG. 2: Students in Stockholm exploring particle collisions in ATLAS

[1] The Learning with ATLAS@CERN project is co-financed by the European Commission, Lifelong Learning Programme (Contract number 143719-GR-KA3MP)

can provide a catalyst for learning. Schools, universities and science centres can act as mediators, organising information – tailored to the needs of their communities – across scientific disciplines and providing tools for understanding complex scientific research, making science understandable and interesting to the public. Bringing together expertise from frontier scientific research and educational research in formal and informal science learning, along with user communities across Europe, the *Learning with ATLAS@CERN* consortium designs, develops, tests, implements and disseminates an innovative pedagogical framework that supports the creation of effective "dialogue" between scientific research and communities, at the moment that the new gigantic detector ATLAS has started operation at CERN, to explore the fundamental building blocks and forces of nature, and to probe deeper into matter than ever before. The project proposes a reversal of science teaching pedagogy from mainly deductive to inquiry-based approach that provides the means to increase interest in science. The proposed approach emphasizes curiosity and observations followed by problem solving and experimentation in both real and virtual settings. These pedagogical concepts and learning practices are addressed by implementing a set of missions (learning scenarios) tailored to the needs of the diverse groups of learners, employing advanced and interactive visualization technologies and also personalised ubiquitous learning paradigms in order to enhance the effectiveness and quality of the learning process. In the framework of these missions, users are able to use a series of educational analysis tools that allow them to manipulate data and make their own discoveries. A web-based educational environment (www.learningwithatlas-portal.eu) has been developed to facilitate the proposed process. The *Learning with ATLAS@CERN* educational environment provides access to near real-time data and interactive analysis tools, 3D and 2D animations of physical processes in a game-like approach, teacher-resources, student-centred materials, applications for educational projects and collaborative activities. Most of these resources already exist; in the framework of the project the consortium presents value-added services to increase the utility of existing programmes through integration, coordination and, where appropriate, archiving. The project pilots and demonstrates the *Learning with ATLAS@CERN* approach in schools, universities and science centres in Greece, Finland, Sweden, Austria, UK and at CERN and through a systematic validation process it tries to develop a structured set of guidelines and recommendations on how effective collaboration between researchers and the educational sector (formal and informal) could create valuable and meaningful learning experiences for all, fostering exploration, discovery, curiosity and collaboration. The whole process of the project is documented in its main outcome, the *Learning with ATLAS@CERN Guide of Good Practice*. The guide emphasizes on a new way of learning about science that reflects how science itself is done, on inquiry as a way of achieving knowledge and understanding about the world. ■

▲ **FIG. 3:** Presentation of the ATLAS Experiment for students



▼ **FIG. 4:** Learning with ATLAS@CERN

Sofoklis A. Sotiriou and **Angelos Lazoudis**, Research and Development Department, Ellinogermaniki Agogi, Greece

4th Forum Physics and Society: Science Journalism and Scientific Communication

The Forum Physics and Society (FPS) aims at establishing a more active EPS role in the relation of physics to society, taking seriously the challenge of maintaining a strong and critical dialogue between physicists and decision makers from policy and economics.

FPS aims at catalyzing the dialogue through workshops and meetings, gathering decision makers and physicists to put the spotlight on topics of interest to both society and to the physics community. The fourth Forum Physics and Society (FPS) assembly took place in El Escorial, Madrid, Spain 21-23 October 2010, following earlier Fora in Graz, Austria (2006), Zakopane, Poland (2007) and Ratnieki, Latvia (2009).

The El Escorial forum addressed the overall topic of physics and science communication, dealing with three topics (i) Journalism and Communication of Science, (ii) The role of electronic media and scientific responsibility and (iii) Science communication, a tool for recruiting new students.

The meeting format consisted of select keynote speeches and panel discussions blended with workshops, formulating written recommendations for the European Physical Society to implement among its national members, divisions and groups. 30 participants with a proven interest in the topic participated and contributed with their insight.

Overall the Forum recognized a challenge for physics (and science) in its ability to communicate with its stakeholders. The fiscal crisis has clearly demonstrated the vulnerability of the science endeavour which after a period with stable growth, now faces an uphill battle for regaining stable support and recognition. Common treads for all three working groups, as well as in the keynote presentations thus were the notion of scientific social responsibility and its manifestations in the interface between science and society, the renewal of the science system through new talented students coming into physics and, finally, the inability of the Forum fully to grasp the new possibilities available in social media. One basis of all discussions was the triangular relationship between the scientists (generation of results and information), the various media (transfer of information) and the public and its perception of science.

What can be done for Science Journalism?

It was generally agreed that the aim of science journalism has several dimensions of which the most important are

- To influence locally politicians and parliamentarians
- To "educate" and empower a general audience using modern media and
- To ensure that science is also considered a cultural expression.

The discussion on science journalism focused on the new economic and technical constraints set on science journalism in many countries, leading to quality being a subject put under pressure. The Forum noted, that

- Investigative journalism takes time and effort. Modern media are less and less prepared to pay for it
- Journalists normally do not have a scientific background, nor time to keep up with the pace of modern science
- There is a tendency for broadcast media to become more trivial – entertainment rather than information
- Journalists should not be dependent on public relations (PR)
- Over-reliance on the citation index results in the PR machine fuelling the choice of research topic, and creates a vicious cycle

The Forum further noted that quality science journalism could be an important component in addressing the problem of the general public lacking scientific understanding with declining emphasis on science teaching in schools as an evil circle. Based upon these reflections the Forum recommends that EPS takes the following actions:

EPS Website

- Establish a dedicated website as a resource for science journalists and as a portal
- Establish and post on the website a network of experts to offer information to journalists on different fields
- For topical issues (*e.g.* volcanic ash, earthquakes, energy, etc.), organize a debate among well qualified experts, and post on the website
- Website could also broadcast other interesting science events – lectures, debates etc
- Communicate exciting news by all possible media, incl. Twitter

Learning opportunities

- Organize regular workshops and summer schools for scientists and journalists to help scientists present their research more accessibly, and journalists get a better understanding of scientific issues. Attending the summer school would enhance mutual understanding
- Provide opportunities for journalists to spend time at a research facility to get insight into the world of research

- Advertise summer schools and internships through the website and all forms of information channels, including Twitter
- Provide funding to enable journalists to attend summer schools or undertake internships through a fellowship program

Citations cycle

- Identify alternative mechanisms for evaluating research – a topic for a future Forum

These actions require EPS to focus its attention more on the development of its website, with contributions from national societies. Investments are required to set up the website, and dedicated staff to maintain it.

Science and social networks

New ways of social interactions

The Forum worked intensely with this topic, realizing that social networks mainly are expressions of the younger generation. The Forum, however, realized the immense importance of these new ways of communicating, using platforms where information can be posted, shared and searched in real time. It greatly benefitted from invited social scientists specializing in these interactions as well as from national societies recently having launched such media.

The stakeholders in this transformation of EPS communication strategy is

- The EPS science community
- The young generation members who are already connected
- Society at large expecting pay-back
- The EPS office, which must take ownership

The Forum discussed several ideas and ways in which such development could be advanced, among them:

- Community managers in the EPS office – moderator role (1 h/day)
- Networks of Twitters (science news, physics, young generation,..)
- Link new social networks to EPS website
- Ensure bridges to outside community, define small group of moderators
- Measure feedback, analyse and understand networks mechanisms
- It's a novel philosophy; do not "pick a winner"
- EPS not in control – attempt to guide access points instead

The Forum realized the immense importance of these new ways of communicating

Based upon this discussion the Forum specifically recommends that EPS enter social networks now by introducing the following actions:

- Establish professional community manager at EPS-Mulhouse
- Nominate smaller group of topical managers among membership
- Establish links to physics student bodies
- Establish links to existing EPS divisional networks and member societies

As a learned society of scholars, EPS has a special responsibility in maintaining the classical virtues of science. EPS policies must therefore be developed and include best practice for navigating on social networks, however, the Forum recommends EPS to jump first and analyse later! The jump into the new social media is complex. The transformation of communication strategy to include new social networks therefore must be planned carefully. The Forum advises to follow these leads in the early phases:

- Launch Twitter site and similar site, now!
- Monitor development – seek collaboration with social scientists
- Encourage members to participate
- Let the outside know about your networks and follow key Twitters actively

Mobilization for science

What can be done for attracting young people into science and science education?

The Forum carefully considered actions to be adopted by EPS in this topic which already has been the topic of several EPS initiatives. The Forum recognizes that recommendations are of a general nature and thus hard to implement. Specifically the Forum recommends that

- EPS should advocate to governments to set targets for confident, qualified and devoted STEM (science, technology, engineering and mathematics) teachers in schools at the appropriate levels
- Because science is an essential part of our culture and existence, STEM should be given appropriate time in education programs and curricula
- Primary school teachers should have training in science and physics, so they can incorporate it in their lessons in a proper way
- High school teachers must be educated in didactics (teaching abilities) as well as in an academic physics system, based on experimental work. Schools must have conditions and equipment for experiments, inside ►

▼ A distant view of El Real Monasterio de El Escorial and outside classroom/laboratory with ample time allocated

- A module related to communication of science should be incorporated at University level (bachelor, masters and doctorate levels).

In addition, the Forum expressed the opinion that going back to the future using science museums and other interactive exhibitions is important and that universities should

- preserve the heritage, in collaboration with science museums and that
- the heritage should be presented, in a physics history context, as a tool to motivate students for physics learning, that
- history courses should include the history of science and technology.

Going back to the future using science museums and other interactive exhibitions is important

Finally, Governments should take actions, as has happened in some countries already, in

- supporting and encouraging Science Agencies in increasing the promotion of Scientific and Technological Culture, implying
- creating local Science Learning Centres and implementing communication science programs at a national scale
- with time this action should create conditions for local initiatives in a bottom up approach. ■

Ove Poulsen, former President of the EPS (DK)
Christophe Rossel, President of the Swiss Physical Society CH)
Gerardo Delgado Barrio, Chairman of the Forum (ES)

EPS-QEOD Europhoton conference

2010, Hamburg, Germany

The 4th EPS-QEOD EUROPHOTON conference took place from August 29 to September 3, 2010 at the University of Hamburg (DE). EUROPHOTON 2010 continued the biannual series of meetings- held in Lausanne (CH, 2004), Pisa (IT, 2006), and Paris (FR, 2008).

The conference was organised by the European Physical Society and the University of Hamburg in cooperation with the Quantum Electronics and Optics Division (QEOD) of EPS and attracted as much as 280 attendees from 27 countries all over the world.

World-renowned researchers discussed the latest breakthroughs and hot topics in the field of solid-state, fibre, and waveguide coherent light sources. The technical programme included keynote, invited and selected, peer reviewed contributed papers encompassing the field of solid-state lasers, waveguide and fibre devices as well as related photonics. A total of 178 accepted contributions covered fundamental aspects, emerging technologies, device development, systems, and applications.

An integrated 1½ - day summer school on "Frontiers of solid-state light sources" for PhD students and post-docs addressed the educational aspects for young scientists.

▲ University of Hamburg, main building

The summer school with 6 highly ranked international speakers attracted 150 attendees in total, from which 90 attendees have been PhD students. A poster competition was organised to award the best 2 posters presented by research students.

Further highlights of the conference have been a public evening lecture celebrating the 50th birthday of the laser (LASERFEST) with the speaker Prof. R.L. Byer from Stanford University (USA) and a special symposium on "High power lasers for materials processing" where the focus was on high power fibre, solid-state, and semiconductor lasers with related applications. Within the special symposium the EPS invited keynote speaker Prof. R. Poprawe from ILT Fraunhofer Institute Aachen (DE) presented a talk on "New lasers enabling next generation microprocessing"; see article in annex of the present EPN issue www.europhysicsnews.org/articles/epn/olm/2011/01/epn_42-1/epn_42-1-olm1.html.

The 5th EUROPHOTON conference will be held in 2012 at KTH Stockholm / Sweden. ■

G. Huber, University of Hamburg, Germany General Chair

12th EUPEN general forum
'New ways of teaching physics'

The second project year (2009/10) of the WG2 of the STEPS TWO academic network culminated with the 12th EUPEN General Forum EGF2010 'New Ways of Teaching Physics' on 2/5 September 2010 at the Université P. & M. Curie (UPMC) in Paris (FR).

The forum started by placing in perspective the whole set of 'technology' tools (simulations, on-line tutoring, demonstrations, videos, interactive lectures, electronic assignments) in physics education and B. Mason (Oklahoma) presented *'The ComPADRE library'*, an example of a network of free on-line resource collections supporting the physics education community.

During the preparatory Workshops, on 14/16 May 2009 in Eindhoven (NL) and on 3/5 June 2010 in Sofia (BG), a task group of WG2 prepared an extensive questionnaire. The STEPS TWO partners were asked for a compact description of their 'new methods' and materials of student-centred and project/problem based learning. The results were presented and the ways to make them available on the web were discussed. Very instructive was M. Birch's (Manchester) interactive lecture in teaching *'Dynamics'* with a real demonstration of the use of (voting) 'clickers'. Feedbacks from students of various levels were discussed. The facet on Peer Instruction was commented by one of her students. As a physicist in Corporate Communications at SIEMENS AG, Frank S. Becker gave his view on the physicists' formation with respect to the labour market.

A presentation and a lively visit of the three large multimedia facility sites within the campus of the University were organized.

A very innovative way of assessing the educational process, including the multimedia resources, was presented by E. Sassi (Napoli). One discussed how the educational potential could be measured with the help of three didactical parameters/indicators: scope, pedagogical effectiveness and transformation potential. A student clearly showed the impact of the 'tool/vector', project work, when being a physics master exchange student (at UCLouvain-la-Neuve). Finally a representative from ESU (European Students Union) explained the vision and the contribution of his association in the spreading of the student-centred learning philosophy.

S. Feiner-Valkier (Eindhoven, chair of WG2) presented the first results of the pilot try out of multimedia evaluation collected by some 10 volunteering members of WG2. Indeed a few multimedia, appearing on the WG's website, were tested by a teacher and a group of students. The WG2 urges all partners to expand this evaluation in order to arrive at reasonable statistics. Afterwards there was ample time to take active part in some of the more than 30 contributions of the two interactive sessions. For the first time such sessions were organized, whereby forum participants had the opportunity to present interactive 'posters', on-line. Most of the participants enjoyed this initiative and they simultaneously got a lot of profit in seeing, using and discussing these contributions. A few contributions were complemented with a paper poster supporting the tool with useful guiding information.

I found it a very good practice asking all participants filling in two anonymous evaluation forms

The chairs of the three STEPS TWO WGs resumed the position of their former and future activities and L Donà dalle Rose (Padova) sketched the almost final results of the CoRe2 project.

I found it a very good practice asking all participants filling in two anonymous evaluation forms: one whereby they had to assess the didactical importance of the contributions to the interactive sessions they were able to attend and one to evaluate all the speakers at the forum, as well as to formulating suggestions for improving the actions of WG2.

We eagerly look forward to next year's EGF2011 General Forum *'Preparing Good Physics Teachers'* and Teacher Education Workshop to be held 28/31 August 2011 in Limassol (CY). ■

Hendrik Ferdinande,
Physics & Astronomy, Universiteit Gent (BE)

▼ The poster session at the Atrium of the Pierre and Marie Curie University (UPMC) in Paris

EPS Liquid Matter Prize 2011

Awarded to David Chandler

David Chandler, University of California, Berkeley will receive this prize at the 8th EPS Liquid Matter Conference,September 6-10, 2011, in Vienna, Austria (http://lmc2011.univie.ac.at).

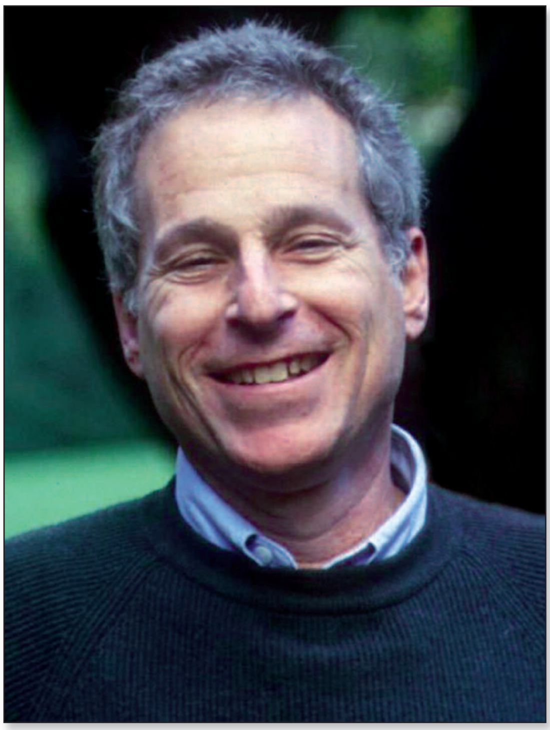
These triennial conferences bring together scientists working on all aspects of the liquid state including soft matter and biophysics.

Previous awardees were J-P. Hansen (2005) and H.N.W. Lekkerkerker and P.N. Pusey (2008).

Chandler, recognized as one of the leading liquid matter theorists worldwide, is awarded the Prize *"for seminal works that have enhanced our understanding of the molecular nature of liquid matter, including highly original and influential theories of microscopic structure, chemical equilibrium and kinetics, quantum processes in fluids, hydrophobicity and vitrification"*.

After graduation in Chemistry at MIT and a Ph.D. in Chemical Physics from Harvard, Chandler joined the University of Illinois, Urbana-Champaign, becoming full professor in 1977. He spent two years at the University of Pennsylvania before joining UC Berkeley. Chandler's domain is statistical mechanics; he applies it masterfully to gain penetrating insights into the microscopic structure and dynamics of liquid matter.

▲ © EPS-LMC



▼ David Chandler

Early in his career Chandler developed, with H. Andersen and J. Weeks, a quantitative theory of the structure and thermodynamics of simple liquids based on molecular packing and a perturbative treatment of attractive interactions. The WCA theory is regarded as a basic equilibrium theory of the liquid state. Chandler and co-workers introduced the reference interaction site model (RISM) which provided the first successful description of the structures of polyatomic liquids and led his student K. Schweizer to a molecular theory of polymeric melts.

Chandler introduced techniques for analyzing chemical equilibrium and dynamics in condensed matter. With B. Berne he performed the first computer simulations of such processes and with P. Wolynes developed quantum mechanical versions providing understanding of electrons in liquids, electron transfer in proteins, and of nuclear vibrations and tunnelling in liquid phase chemical dynamics.

In the late 70's Chandler and L. Pratt developed a molecular theory of the hydrophobic effect, *i.e.* the nature of the organization of water near an oily species. Later, in 1999 with K. Lum and J. Weeks, Chandler tackled larger length scales and showed how a low-density water region can develop along extended oily surfaces, providing a potential mechanism for hydrophobic assembly.

In 1997-2001 Chandler, with P. Bolhuis, C. Dellago and P. Geissler, devised the transition path sampling method for computer simulations of rare events in complex systems. This method was applied in many contexts including solvated biomolecules, nucleation processes and aging of meta-stable systems. The underlying ideas extend far beyond chemical dynamics: the recent approach of Chandler and J. Garrahan to glassy dynamics is based upon the geometry of trajectory space and promises a unified picture of glassy phenomena.

In recognition of his research accomplishments, Chandler received numerous awards including election to the US National Academy of Sciences. He is also the author of "Introduction to Modern Statistical Mechanics", equally popular among students and practitioners in the field. ■

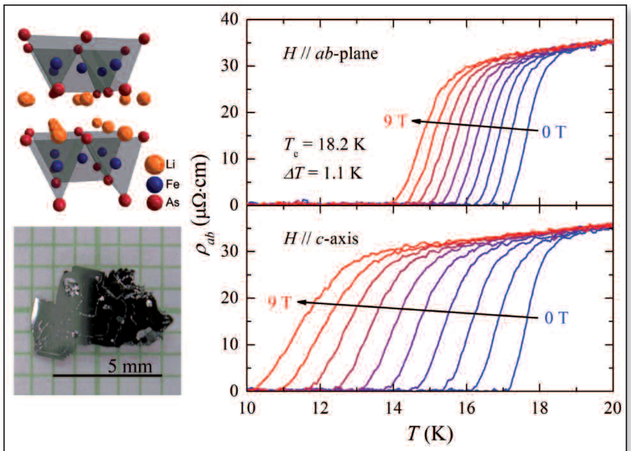
C. Dellago,
Chair EPS Liquids Board
R. Evans,
Chair Prize Committee

Highlights from European journals

CONDENSED MATTER

A very **clean Fe-based** superconductor might show up **new ground states**

Iron-based superconductors, discovered in early 2008 and exhibiting superconducting transition temperatures T_c as high as 57 K, currently draw focused attention in the condensed matter community. Among various structural forms known, LiFeAs represents the prototype of the "111" compounds with several unique properties: superconductivity without chemical doping, thus being subject to the least disorder effect, no Fermi surface nesting for inducing an antiferromagnetic spin density wave fluctuation as a possible pairing glue for superconductivity. Moreover, the structure contains a FeAs layer sandwiched by the double Li layers so that the cleaving can be easily done in the Li surface without having surface reconstruction, an important favorable condition for surface-sensitive investigations.



▲ The ab-plane resistivity under magnetic fields for two different crystallographic directions of a LiFeAs single crystal grown by the Sn-flux method with T_c=18.2 K. The crystal structure and a typical picture of the grown crystals are also displayed.

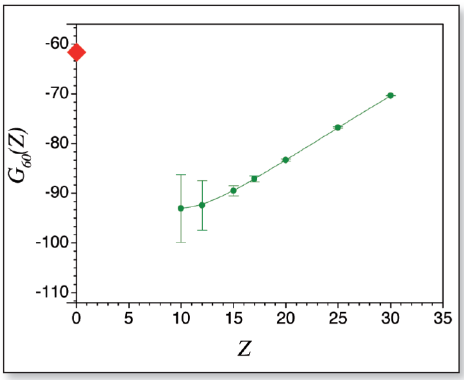
Due to the highly volatile nature of Li, the high quality single crystal growth has only recently been achieved. The present research reports the first successful growth of a large area single crystal of LiFeAs by using Sn flux, producing T_c = 18.2 K with a narrow transition width ΔT_c = 1.1 K as well as a relatively large residual resistivity ratio, ~ 22-35. Upon measuring transport under high magnetic fields for two crystallographic directions, *H // ab*-plane and // *c*-axis, the system exhibits a moderate anisotropy of 2.3 near T_c, consistent with a prediction of a reduced anisotropy caused by correlation effects. Based on several recent proposals which point out the possible realization of a p-wave pairing symmetry and a Fulde, Ferrell, Larkin & Ovchinnikov state, it is envisioned that the present cleanest, large LiFeAs single crystal offers an unprecedented opportunity to find new, exotic ground states of correlated electron systems in the Fe-based superconductors. ■

▮▮▮ **Bumsung Lee**, **Seunghyun Khim**, **Jung Soo Kim**, **G.R. Stewart** and **Kee Hoon Kim**,
'Single-crystal growth and superconducting properties of LiFeAs', *EPL* **91**, 67002 (2010)

ATOMIC AND MOLECULAR PHYSICS

Two-loop self-energy correction in hydrogen Lamb shift

The results of the recent measurement of the Lamb shift in muonic hydrogen [R. Pohl et al., Nature 466, 213 (2010)] created what is now widely known as "the proton charge radius puzzle". The charge radius of the proton derived in this experiment turned out to be 4% smaller than that obtained from the Lamb shift in ordinary hydrogen. This discrepancy is very surprising, given that the underlying theory, QED, is one of the most precise and well-tested fundamental theories. Half a year has passed since the announcement of the unexpected results and theoreticians have checked and double-checked QED calculations in both muonic and ordinary hydrogen. However, despite all the efforts, no plausible ideas about the cause of the discrepancy have been suggested, and the puzzle remains unsolved.



◀ Comparison of the results of the numerical all-order calculations as a function of the nuclear charge Z (dots and solid line) and the analytical perturbative result (diamond on the y-axis) for the higher-order two-loop self-energy correction.

This paper deals with the most problematic QED effect in ordinary hydrogen, the two-loop self-energy correction. It is this effect that induces the main theoretical error in the hydrogen proton charge radius. Previous calculations have demonstrated a disagreement between two different methods: the one based on the perturbative expansion in the binding nuclear field and the one including binding effects to all orders. Though this disagreement is too small to explain the puzzle, it still needs to be resolved to ▸

clarify the uncertainty of the hydrogen proton charge radius. In this paper, a new technique is developed for calculations of the two-loop self-energy diagrams treated in the mixed coordinate-momentum space. This technique increases the numerical accuracy of the results, reducing without eliminating the disagreement between the two approaches (Fig.). ■

V.A. Yerokhin,
'The two-loop self-energy: diagrams in the coordinate-momentum representation', *Eur. Phys. J. D* **58**, 57 (2010)

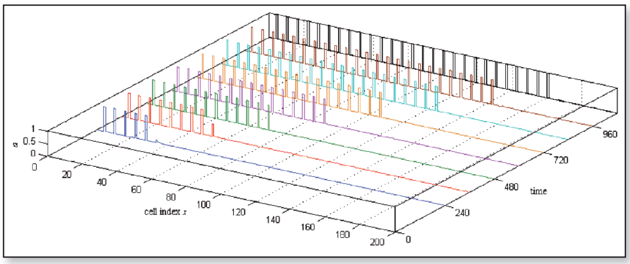
generically select a unique pattern, but the P&L model operates in a strongly non-linear regime where the final pattern depends on the initial conditions as well as on parameter values. This study highlights the important role that cellularisation and cell-autonomous feedback can play in biological pattern formation. ■

M.W. Pennington and **D.K. Lubensky**,
'Switch and template pattern formation in a discrete reaction-diffusion system inspired by the Drosophila eye', *Eur. Phys. J. E* **33**, 129 (2010)

BIOPHYSICS

Switch and template pattern formation as in the **Drosophila eye**

Biology provides the physicist with a stunning variety of patterns to explore, and several fundamental ideas in the physics of pattern formation, such as Turing instabilities and the clock-and-wave-front mechanism, are rooted in studies of biological systems. It remains unclear, however, whether these classic concepts can explain the emergence of patterns in most biological systems, or whether new and different mechanisms remain to be discovered.



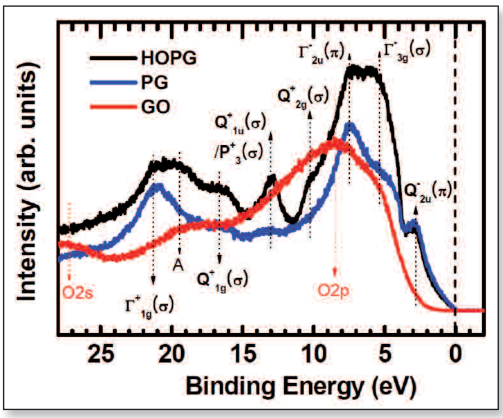
▲ Spatio-temporal portrait of a moving front in a simple model of switch and template pattern formation. The front moves with a constant speed, leaving behind a highly non-linear, periodic pattern. (For clarity, the spatial patterns at different time points are plotted in different colours.)

Here, the authors, at the University of Michigan, Ann Arbor, examined a spatially discrete, three variable reaction-diffusion model inspired by the interactions that create a periodic pattern of gene expression in the Drosophila eye imaginal disc. This model is capable of creating a regular pattern behind a moving front, as observed in eye discs, through a novel "switch and template" mechanism. In order to better understand this mechanism, the authors performed a detailed study of the model's behaviour in one dimension, using a combination of analytic methods and numerical searches of parameter space. Using this approach, the authors find that patterns are created robustly, provided that there is an appropriate separation of time scales and that self-activation is sufficiently strong. Moreover, the paper presents explicit expressions in this limit for the front speed and the pattern wavelength. Moving fronts in pattern-forming systems near an initial linear instability

CONDENSED MATTER

Valence band of **graphite oxide**

Graphite oxide (GO) has been the subject of intense study for its use in producing cheap and vase amounts of graphene by reduction through chemical or physical methods. Reduced graphite oxides have been used in graphene-based applications such as transparent conducting film (TCF), flexible displays, field effect transistors (FET), supercapacitors, and batteries. Therefore, it is essential to study the fundamental electronic and structural properties of graphite oxide to exploit its possible applications.
This paper investigated the valence band structure of graphite oxide by photoelectron spectroscopy for the first time. The typical sp^2 hybridization states (π and σ) found in graphite were also observed in graphite oxide. However, the π state near the Fermi level disappeared because of bonding between the π and oxygen-related states originating from graphite oxide, indicating electron transfer from graphite to oxygen and resulting in a downward shift of the highest occupied molecular orbital (HOMO) state to the higher binding energies. The band gap opening increased to about 1.8 eV, and additional oxygen-related peaks (O_{2p} and O_{2s}) were observed at 8.5 and 27 eV in graphite oxide. The work function of graphite oxide was also first measured using the kinetic energy cut-off of the secondary electrons to be 5.9 ± 0.1 eV. These research results can improve fundamental understanding of graphite oxide for its possible applications. ■



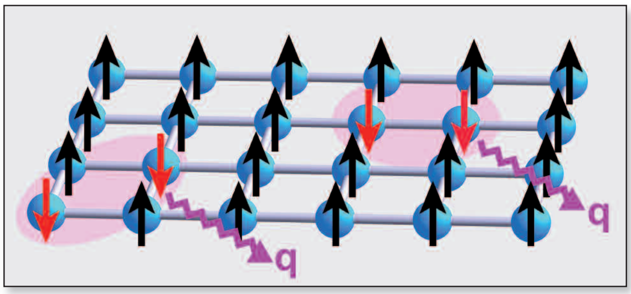
◀ The valence band of HOPG (Highly oriented pyrolytic graphite), PG (precursor graphite), GO (graphite oxide) with a photon energy of 130eV.

Hae Kyung Jeong, **Cheolsoo Yang**, **Bong Soo Kim** and **Ki-jeong Kim**,
'Valence band of graphite oxide', *EPL* **92**, 37005 (2010)

CONDENSED MATTER

Bose-Einstein condensation of **bound magnon pairs**

Strong quantum fluctuations can destroy conventional dipole-type magnetic ordering. A quantum magnet remains, then, in a disordered spin-liquid state down to zero temperature. The enhanced fluctuations may also stabilize magnetic analogues of liquid crystals, states with partially broken rotational symmetries characterized by tensor order parameters. The prime candidates for such exotic spin-nematic states are frustrated magnetic systems with competing interactions.



▲ In the spin nematic state, bound pairs of magnons (down spins shown by red arrow) propagate coherently in the polarized ferromagnetic background.

Here, we investigate theoretically a microscopic mechanism for the spin-nematic ground state based on the competition of ferro- and antiferromagnetic interactions. In a strong magnetic field, local magnetic moments become completely polarized. Elementary excitations are single spin-flips or magnons. In the majority of quantum antiferromagnets spin-flips repel each other. Upon decreasing external field this leads to single-particle condensation, which can be regarded as an analogue of the Bose-Einstein condensation discovered for cold atomic gases in optical traps. Various exotic quantum states of bosonic particles find their analog in conventional magnetic structures.

The above conventional scenario changes if some of the exchange bonds are ferromagnetic. In this case, spin flips gain the interaction energy by occupying two adjacent sites. This may lead to formation of bound magnon pairs. Because of their lower energy, the bound pairs start to condense prior to the onset of single particle condensation (Fig.). We have developed the microscopic description of the Bose condensation of bound magnon pairs, which form a quantum state analogous to the condensate of electron pairs in superconductors. Our theory predicts the presence of such a spin-nematic phase in the frustrated chain material $LiCuVO_4$. The pulsed-field measurements on $LiCuVO_4$ and other related compounds should lead to the first observation of this exotic off-diagonal order in solid-state systems. ■

M.E. Zhitomirsky and **H. Tsunetsugu**,
'Magnon pairing in quantum spin nematic', *EPL* **92**, 37001 (2010)

PLASMA

Self-organized plasma jet at atmospheric pressure

Miniaturized non-thermal jet plasmas belong to the class of microplasmas characterized by dimensions below 1 mm. They represent an emerging technique for local surface treatment at atmospheric pressure such as surface modification and the deposition of thin functional coatings (for corrosion protection or gas diffusion barrier). The deposition of films with controlled quality requires the knowledge of the basic mechanisms, both plasma kinetics and flow dynamics that sustain and stabilize the gas discharge. This calls for a measure of the plasma parameters, validated by a suitable model. The plasma source studied here is a capacitive coupled capillary jet (27.12 MHz) operating in a distinctive regime where self-organized discharge patterns develop (Fig.: time-averaged top view). This discharge regime along with the plasma source geometry puts the device in a prime position for a coating process at atmospheric pressure. The paper describes a first step towards a thorough plasma physical description of the discharge dynamics and the energy transport by determining the electron concentration in the active discharge zone. Two independent approaches were used, spectroscopic measurements of the broadening of Balmer H_β and H_γ lines and a time-dependent, 2D fluid model of a single discharge filament. Electron concentrations between 2.2 and $3.3\times10^{14}cm^{-3}$ have been obtained after separating the relevant spectral line broadening effects. The fluid model has confirmed these results. The relatively high electron concentration in the active jet zone can be explained by the contraction of the discharge into single filaments. The self-organization makes these filaments deterministic but not stochastic. Their steady behaviour furthermore supports the establishment of a larger concentration of excited atoms, especially metastable atoms, leading to enhanced ionization. ■

▲ The photograph of the capillary jet in the self-organized regime (four filaments, axial view, diameter 4 mm, exposure 1 ms).

J. Schäfer, **F. Sigeneger**, **R. Foest**, **D. Loffhagen** and **K.-D. Weltmann**,
'On plasma parameters of a self-organized plasma jet at atmospheric pressure', *Eur. Phys. J. D* **60**, 531 (2010)

INTERVIEW WITH MICHAEL E. FISHER

José M. Ortiz de Zárate - Complutense University and Royal Spanish Physical Society - DOI: 10.1051/epn/2011101

In June 2010 Professor Michael E. Fisher, from the University of Maryland, visited Madrid for the ceremony of the "Frontiers of Knowledge Prizes" that are annually awarded by the Foundation of the Banco Bilbao Vizcaya Argentaria (FBBVA[1]). Prof. Fisher shared the 2010 prize in the category of "Basic Sciences" (400 k€) with Prof. Richard N. Zare from Stanford University.

Prof. Fisher is considered, together with Kenneth Wilson, Leo Kadanoff and Ben Widom, one of the fathers of the Renormalization Group (RG) Theory, probably the most important theoretical development in Statistical Physics in the last quarter of the 20th century, that deserved a Nobel Prize in Physics (1982, to Ken Wilson). For his work in this field, Prof. Fisher was awarded with the Wolf Prize (1980, shared with Ken Wilson and Leo Kadanoff), the Boltzmann Medal (1983) and the Onsager Prize (1995). During his visit to Madrid, Prof. Fisher talked at length with the Royal Spanish Physical Society (RSEF), and in what follows we reproduce part of that meeting as an interview. Most of Prof. Fisher's comments are of general interest. Although some refer more specifically to the situation in Spain, we think they may also be interesting for the wider audience of Europhysics News.

You are well known mostly for your contributions to what nowadays is known as the Renormalization Group Theory of critical phenomena. You may want to share with our readers recollections of those years (1970-1971) at Cornell, and about the importance of collaboration and multi-disciplinarity in the birth of this theory.

Well, how should I answer this question? As a practicing scientist one should know that one's memory in such matters is seldom reliable! Secondly, one should be concerned to give proper credit to one's friends, teachers, collaborators and competitors. For these reasons, some years ago I published a paper [1] where you can find my recollections of that time, and where I endeavored to give appropriate credit to everyone involved.

But perhaps some of the background to the events may be of interest?
I did my thesis in King's College London on analogue computers. After finishing my Ph.D. I found there were few prospects in that field in Britain. I became interested in critical phenomena through Cyril Domb who became Professor in Theoretical Physics at King's College at that time, and took an interest in me.
Initially, however, through his contacts with Aharon Katchalski at the Weizmann[2] Institute I was introduced to polymer physics. In that connection, especially from a paper by Robert Rubin (at what was then NBS[3]) I learned that four spatial dimensions is a special, borderline, case. This knowledge later proved valuable when applied to critical phenomena.
At that time the famous 1944 paper by Onsager where he solved the two-dimensional Ising model exactly [2] was still fresh. Many people were trying to solve it in three dimensions. But I had no such ambitions. Rather, as often when I read a new paper, instead of trying to follow in detail each step, I think about the solution, asking what it tells me and how it might be generalized. Then, combining what I learned from Onsager's paper with what I gathered from Cyril Domb, I arrived to some ideas –essentially scaling concepts– that proved similar to what, independently and over the same period, Ben Widom at Cornell[4] and Leo Kadanoff (then in Illinois[5]) were developing.
Widom read my papers and invited me to visit him. And that is how I eventually ended up in the Chemistry Department in Cornell (with a courtesy appointment in Mathematics). At Cornell Ben and I ran an interdisciplinary seminar where many people came from other fields. Among them was Ken Wilson, who arrived in the Cornell Physics Department at more or less the same time I arrived in Chemistry. Ken Wilson had been a very bright student of Murray Gell-Mann at Caltech[6], and was a very open-minded person. He attended and spoke at our seminar and both Ben Widom and I discussed critical phenomena and scaling with him. In some sense, Wilson learned about critical phenomena from us.
And this was, more or less, the cradle in which Renormalization Group (RG) theory was born! Perhaps, I can add, to my personal credit, my contribution to the epsilon-expansion. I knew that four dimensions (and above) was a special situation where, in some sense, the Ising model can be solved simply. Thus, it occurred to me to suggest an expansion of the theory for dimension d in powers of $\varepsilon=4-d$. I recall very well discussing this issue with Ken Wilson; and this later turned out to be an important ingredient for many (but by no means all) explicit applications of the RG.

In your opinion, the theory of critical phenomena has to be considered nowadays as essentially "closed", or is there room where relevant contributions are still possible?
If you had asked me this question say six or more years ago I may well have answered: "Yes, the theory of critical phenomena is now rather well understood and so may be regarded as closed". However, during the last decade, some intriguing new developments have arisen.
One is related to multicritical points, especially those associated with quantum phase transitions as one sees at low temperatures. Thus the appropriate description of the many phenomena seen in high T_c-superconductors, still seems to raise open questions. Then there is the issue, of long interest to me, concerning the possible existence of "supersolids", exhibiting both long-range crystalline order together with intrinsically quantum-mechanical ODLRO, or "off-diagonal long-range order". The path-breaking experiments of Moses Chan [3] in Penn State University[7] are the prime stimulus. And the books by Subir Sachdev [4] and by Xiao-Gang Wen [5] pose many open theoretical questions: First there is the issue of new types of phases of matter, second of the phase transitions between them and, then, of the associated critical phenomena including the dynamical aspects.
But even in what may be regarded as the "classical theory of critical phenomena" new issues have arisen. One is the so-called "complete-scaling theory" formulated with Makis Orkoulas and Yougchan Kim (two of my former postdocs), which has been taken up and applied to fluid mixtures, colloids, *etc.*, by my colleagues at Maryland, Jan Sengers and Mikhail Anisimov. And related to this there are a host of what we are calling "compressible cell models" –many exactly soluble– developed with Makis and with Claudio Cerdeiriña from the University of Vigo, Ourense Campus (where, sadly, they are planning to close the programme in Physics).
So, in summary, there are still interesting and rewarding issues for theoretical research.

In your opinion: What are the most important developments in Statistical Physics during the last decade?
Well, this is a tricky question for me to answer, in particular for the same issue of giving proper credit that we ▸

Notes

[1] BBVA is the second largest bank in Spain, with an important business in Latin America too.
[2] Weizmann Institute of Science, Rehovot, Israel.
[3] National Bureau of Standards, USA Government.
[4] Cornell University, Ithaca, New York, USA
[5] University of Illinois at Urbana-Champaign, Illinois, USA
[6] California Institute of Technology, Pasadena, Los Angeles, USA
[7] Pennsylvania State University, University Park, Pennsylvania, USA

talked about before. And partly because I do not normally think in such terms! Indeed, many interesting things are discovered and new ideas arise; but what will prove of lasting significance on a scale of a decade is often not so clear.

But, anyway, if I have to give an answer I would say that the Jarzynski Relation [6] and subsequent Non-equilibrium Work Theorems are prime candidates. Indeed, a distinguished Russian theorist has remarked that Jarzynski's relation is the only known true formula that does not appear in the volumes of Landau and Lifshitz! [7]. Indeed, Chris Jarzynski has effectively opened up a new field in Statistical Physics. Now, with precision, one can apply Statistical Mechanics not only to equilibrium states, but also to finite rate processes that carry a system from one state to another. It also has provided a new way of looking at the Second Law, which in classical Thermodynamics was always formulated as an *inequality*, but Jarzynski showed that for some processes it can be formulated as an *equality*.

We know that, because of family reasons, you are greatly interested in what happens in Spain. What is your opinion about Physics in Spain?

So, there is Flamenco in Spain and cante hondo; there are bullfights and fiestas; there is the Semana Santa in Seville and the Alhambra in Granada; there is the mosque in Cordoba and the cathedral in Santiago de Compostela; there is pelota in San Sebastián and the jota in Aragón and, here in Madrid, there is the Puerta del Sol and the Plaza Mayor, the Prado, the Retiro, the Rastro and Chamartín de la Rosa where my wife, the youngest daughter of José Castillejo, was born.

And –jokingly– there is Physics too?...

Now seriously, it has been a pleasure and a privilege to give plenary talks at the meetings of the Royal Spanish Physical Society in Jaca in 1993 and, more recently, in Granada in 2007. And I have spoken on science at other venues in Madrid and elsewhere in Spain.

But it is true that in earlier years, after the Second World War, I was sometimes a bit sad at the seeming paucity of Spanish physicists in International meetings. In the fields I know, Britain, France, Germany and the Netherlands were countries with representatives much in evidence. Later came Italy and Scandinavia. In truth, the period after World War II was hard in Europe. But, initially from the United States and later in the aftermath, from European nations came strong public support for Physics. For Spanish scientists, support doubtless grew more slowly.

But now the situation is becoming not so good for most. We may well be back to what it used to be before the War, when money for science, especially for basic science, was provided mainly by wealthy individuals or their Foundations, primarily because they liked the results the scientists achieved with their grants, and believed that the basic sciences, like the Arts, are fundamental for a good society.

What about Physics education in Spain?

I like to think that I know what I don't know! And, also, how to keep silent when my ignorance is at play. But, yes, in this respect I have seen lately in Spain a development that I had previously noticed in some Eastern European countries. Specifically, it is the substitution in Universities and in secondary education of the basic sciences by other supposedly more "applied" subjects. The teaching of applied sciences is, surely, necessary, but I strongly believe it should be done at a master's level, not as a feature of undergraduate education. Consider, indeed, that society changes fast and modern technology even faster. Anybody of my generation, when looking back, is amazed by how society and technology have changed during their own lifetime. Hence, it happens that applied knowledge that today may be very important becomes, in a decade or so, completely obsolete. Only a good education in basic sciences will give our young students the sound foundations required to cope with the future challenges of an ever-changing world.

Many of the readers of our magazine are young physicists. What is your advice to them, in particular about the selection of a subject for graduate studies?

My advice is very simple and is something I have tried to do during my whole life. Do not undertake anything unless you are really interested in it! There are lots of fascinating things to do in Physics, in the other Sciences, in other professions and in the World at large. Your time is precious. Do not waste it! ■

References

[1] M.E. Fisher, *Rev. Mod. Phys.* **70**, 653 (1998)

[2] L. Onsager, *Phys. Rev.* **65**, 117 (1944)

[3] E. Kim, M.H.W. Chan. *Nature* **427**, 227 (2004); *Science* **305**, 1941 (2004)

[4] S. Sachdev. "Quantum Phase Transitions", Cambridge University Press, 1999.

[5] X.-G. Wen. *Quantum Field Theory of Many-body Systems: From the Origin of Sound to the Origin of Light and Electrons,* Oxford University Press, 2004.

[6] C. Jarzynski, *Phys. Rev. Let.* **78**, 2690 (1997)

[7] L.D. Landau and E.M. Lifshitz, *Course of Theoretical Physics* (in 10 volumes). Butterworth-Heinemann.

THE LASER
FROM YESTERDAY (1960) TO TOMORROW

■ **Martial Ducloy** - Former President of the EPS - Former Chairman of the Quantum Electronics and Optics Division - DOI: 10.1051/epn/2011102

Fifty years ago, on the 16th of May 1960, the first laser ("Light Amplification by Stimulated Emission of Radiation") emission was obtained by Theodor Maiman with a flash-lamp-pumped ruby crystal. This observation was the product of a long search, which can be dated back to the early twentieth century.

It combined the development of an optical resonator by Charles Fabry and Alfred Pérot (the "Fabry–Pérot interferometer", in 1897, noted F-P) on the one side and the prediction of stimulated emission of light by Albert Einstein in 1916, from thermodynamic considerations about radiation processes in the blackbody emission, on the other. The rapid advances in high-frequency electronics and radar technology during World War II accelerated the post-war research in microwaves and quantum electronics. It led to the development of optical pumping by Alfred Kastler in 1950, and then to the first demonstration of a MASER ("Microwave Amplification by Stimulated Emission of Radiation"): The first ammonia beam maser was operated by Charles Townes and co-workers in 1954, quickly followed by Alexander Prokhorov and Nicolai Basov. That was the start of what has been called Quantum Electronics. Actually, the laser era started in 1958, when Arthur Schawlow and Charles Townes proposed to extend the maser operating principle towards higher frequencies, into the optical range. This required the replacement of the closed microwave cavity by an open Fabry-Pérot resonator. This idea led to the 1st laser observation by Maiman in 1960. Thereafter the development of lasers was exponential and thousands varieties of lasers have been and are still being developed.

This great variety of lasers involves different materials, wavelengths, sizes and powers, continued or pulsed regimes, etc. What is the common feature for a semiconductor laser diode of micrometric dimensions, a gas laser, a free-electron laser occupying a vast hall, or, for example, the "Laser MegaJoule" (in Bordeaux, France) and the "National Ignition Facility", planned for controlled thermonuclear fusion (in Livermore, USA), which needs several huge buildings? It is the oscillator concept: the laser is a *light oscillator*, combining an amplifying medium with an optical resonator (often of the simple ▶

▲ Laser fountain made for the '50 years of laser' at Laboratoire de Physique des Lasers (Université Paris XIII and CNRS, FR). It illustrates in a spectacular way the guiding of light by total internal reflection inside a water jet. The same principle is at work in low-loss optical fibres as used in optical communication (picture credit Ph. Lavialle).

F-P type, but not necessarily) providing the resonant light feedback necessary to reach the oscillation threshold. An essential ingredient of laser operation is the population inversion needed to yield light amplification, *i.e.*, to establish negative temperatures, in contrast to the usual thermal equilibrium. The huge variety of lasers comes, first, from the large choice of amplifying media; these can be gases, liquids or solids, crystallized or not, such as semiconductors, doped insulators or fibres, dyes, polymers, etc. The variety also comes from the population inversion, which can be obtained via optical or electronic pumping, via energy-exchanging collision processes, etc. This has led to the realisation of many different lasers among which one remembers the first continuous-wave laser, the famous helium-neon laser, realised by Ali Javan and colleagues in 1960; the high power CO_2 laser used for decades in industrial applications; the multiple semiconductor lasers presently used everywhere; the dye lasers, which were the first wavelength-tuneable emitters (of particular interest in basic research); the fibre lasers, etc. The progress in laser materials, in nonlinear optical techniques and the development of laser technology allows laser sources now to cover a wavelength range extending from the far-infrared to the hard X-UV domain.

The main properties of a laser beam originate from the stimulated emission process. The light is generally propagating in a single mode of the resonant optical cavity. This imposes both spatial and temporal coherence to the laser beam, in stark contrast with the emission of traditional light bulbs. The spatial coherence implies high beam directivity and thus a strong brilliance (and intensity) of the beams. Beam directivity is used for alignment procedure as well as distance measurement. A striking example is the earth-moon distance, which has been measured with a precision up to the cm level, thanks to the retro-reflector installed on the moon by the Apollo missions. The beam intensity is used in industrial lasers for machining/micro-machining of materials as well as in surgery/micro-surgery applications.

The temporal coherence has many applications in fundamental and applied sciences.

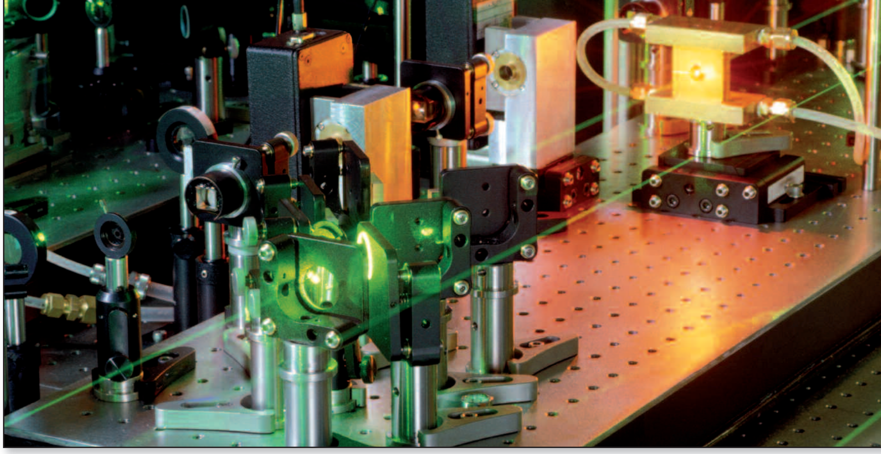
Frequency stabilisation and laser metrology developed very quickly from the early days of the laser, and revolutionized time and frequency standards. The use of He-Ne lasers to measure both wavelength and frequency of a CH_4 transition at 3.39 µm by John Hall *et al.* has yielded the most precise of the various light velocity measurements. Based on this measure, the CCDM[1] decided in 1983 to fix the light velocity and to link to it the time and length standards. Length measurements are now controlled by highly accurate frequency measurements. On the other hand, time standards are regularly improved thanks to the progress in laser sources and cold atoms.

The laser has had a fantastic impact on basic research in atomic, molecular and solid-state physics. In a way, it was at the basis of the renewal of old disciplines (electronics, atomic and molecular physics) from the 1970s onwards: nonlinear optics, high-resolution laser spectroscopy, Raman spectroscopy, measurement of fundamental constants at an unprecedented level of accuracy, laser cooling and trapping, ultra-cold quantum gases and Bose-Einstein condensation, quantum information. The progress in all these fields is a direct consequence of the development of lasers. Eight Nobel prizes since 1964, in physics and chemistry, are directly related to lasers and laser applications. As an example, peculiar properties of lasers rely on the photon statistics of the emitted radiation. The analysis and control of these properties form the basis for the field of Quantum Optics. Quantum Optics can be viewed as a case study in Quantum Physics and dynamical systems, and allows the study under ideally suited conditions of such fundamental concepts as wave-particle duality, Heisenberg uncertainty relations, quantum correlation and entanglement, theory of quantum measurement, decoherence, bifurcations and chaos, squeezing etc. Quantum Optics has opened the way to quantum information and quantum cryptography.

▼ Theodore H. Maiman of Hughes Aircraft Company showing a cube of synthetic ruby crystal, the material at the heart of the first laser. © Hughes Aircraft Company

Note

[1] Comité Consultatif pour la Définition du Mètre, of the "Bureau International des Poids et Mesures" – BIPM - Paris)



▲ Ultra Fast Laser, UCSD © iStockPhoto

In the study of time-dependent phenomena, the development of laser technology has also had a quite impressive impact with the realisation of shorter and shorter laser pulses, lasting now just a few optical cycles. We can now realize pulses below the femtosecond range ($1fs = 10^{-15}s$) and even the hundred attoseconds ($10^{-18}s$). These pulses give access to the domain of fs and sub-fs spectroscopy with its many applications in ultrafast physics, chemistry and biology. For instance, in chemistry, ultra-short laser pulses have been used for the coherent control of physicochemical processes and fs dynamics of molecular reactions, giving access to a stroboscopic picture of atoms and molecules in interaction. Correlated to this shortening in pulse duration, extremely large instantaneous optical powers have been obtained, in the petawatt range ($10^{15}W$) and higher. The corresponding ultra-large electric fields of these lasers are presently investigated to build compact particle accelerators. They may open the door to the observation of nonlinear optics of quantum vacuum (pair creation, etc.). In relation to this, the production of very large energy pulses (higher than the megajoule) is being actively pursued in an attempt to achieve laser thermonuclear fusion by inertial confinement.

The impact of lasers in the socio-economic world and everyday life has been widespread. Technological applications range from communications to aeronautics (like gyro-lasers in airplanes), to medicine and health. For the general public, the most immediate and visible applications are in reading processes: bar codes in supermarkets, the compact disk, DVD, optical disk drives in PC's, etc. In medicine, lasers are used both as a sensitive diagnostic tool and a selective scalpel. Laser micro-dissection is now in common use. From the early laser days, applications in ophthalmology have quickly developed, the principle being to select a wavelength not absorbed by the cornea and able to act inside the eye. Other numerous medical applications include tissue luminescence and DNA decrypting. In a general way, laser spectroscopy allows one to perform selective and accurate *in situ* diagnostics of given species. Such spectroscopy has been applied to remote detection of trace elements in environments as different as upper atmosphere, reaction flames or living tissues. In Earth and atmospheric sciences, LIDAR (Light Detection and Ranging – the laser analogue of RADAR) is commonly used for remote monitoring of pollutants and aerosols. From planes or space, LIDAR is used for 3D scanning of earth surfaces, sea level or archaeological sites. For instance, remote cartography of a Maya site (Caracol, Belize) has been recently performed through the tropical forest, avoiding lengthy terrestrial survey missions. The impact of lasers in long-distance communications has been tremendous. Combined with fibre optics for light guiding (*cf.* Nobel Prize in 2009), lasers have opened the way to the explosion of both the number and the bandwidth of real-time communications, with a hundred-million-fold increase in communication speed as compared to previous electronic devices.

What is the future? It is clear that the course toward miniaturisation will continue. In the mid-infrared range, quantum cascade lasers have been successfully developed. A field that has been opened up already is nanophotonics, which combines laser and nanotechnologies. New laser sources – nanolasers – have appeared, in which laser emission is obtained in a nanometre-size space, via nanosurface light confinement. Extension of the laser concept from light waves to matter waves has been performed starting from Bose-Einstein Condensates, leading to what has been coined "atom lasers". The future of atom lasers and their eventual everyday use will also depend on their miniaturisation.

The laser is emblematic of a successful revolution. At the beginning, the laser could have been (and was) described as *"a solution looking for a problem"*. Fifty years after its discovery, the number of applications in both fundamental science and the socio-economical world is impressive. In terms of number of patents, the laser ranks third in the 20th century (after engines and computers). The laser era is also an archetype of the way scientific and technological revolutions occur, *i.e.*, by unpredictable jumps. It has been said that it is not by trying "to improve candles", that electric light bulbs were developed in the 19th century. Similarly, laser sources have not been discovered by doing research in view of improving flash lamps. Basic research on radiation emission processes, along with technological advances and interdisciplinary approaches, has opened the way to these novel light sources, with unexpected properties. New fields have been opened: optoelectronics, nanophotonics, etc. The lasers are devices now fully integrated in our technological society through tools considered as part of every day life all over the world. Just suppose that all lasers stop working everywhere: all communications (phones, internet…) would stop, PC's would be out-of-use, all financial transactions (ATM, credit cards…) would be interrupted, etc.

In conclusion, the laser story teaches us that basic, curiosity-driven scientific research is a fundamental element of progress for the society, opening new fields of knowledge and applications, which could have never been predicted from project-oriented research. ■

■ L.J.F. (Jo) Hermans – Leiden University, The Netherlands – Hermans@Physics.LeidenUniv.nl – DOI: 10.1051/epn/2011103

Amazing candle flames

Granted: a candle flame is a lousy source of light. For an energy user of some 100 W, its light production doesn't even come close to any modern light source. But other than that, it represents an ingenious piece of technology. Before going into details, we should realize that, when talking about flames, we are talking about chemical reactions in the *gas phase*. We can even illustrate this in a simple way by blowing out a candle, and re-lighting it by sticking a burning match into the stream of smoke above the hot wick. So, we cannot simply light a chunk of candle wax by a match, because its vapour pressure is far too low. Take paraffin, by far the most common wax used in candle production. It consists of a mixture of hydrocarbons, for example C_nH_{2n+2} with n typically around 22 to 25. Such molecules have vapour pressures at ambient temperature far below 10^{-6} bar, much too low to be ignited and – fortunately – low enough for the candles to be stored almost indefinitely. So, for igniting paraffin we must get closer to its boiling point, which is somewhere in the range of 350 to 430 °C.

This is precisely what we achieve by having a wick with some paraffin absorbed. Its heat capacity is so small that its temperature can be raised by a burning match in just a second.

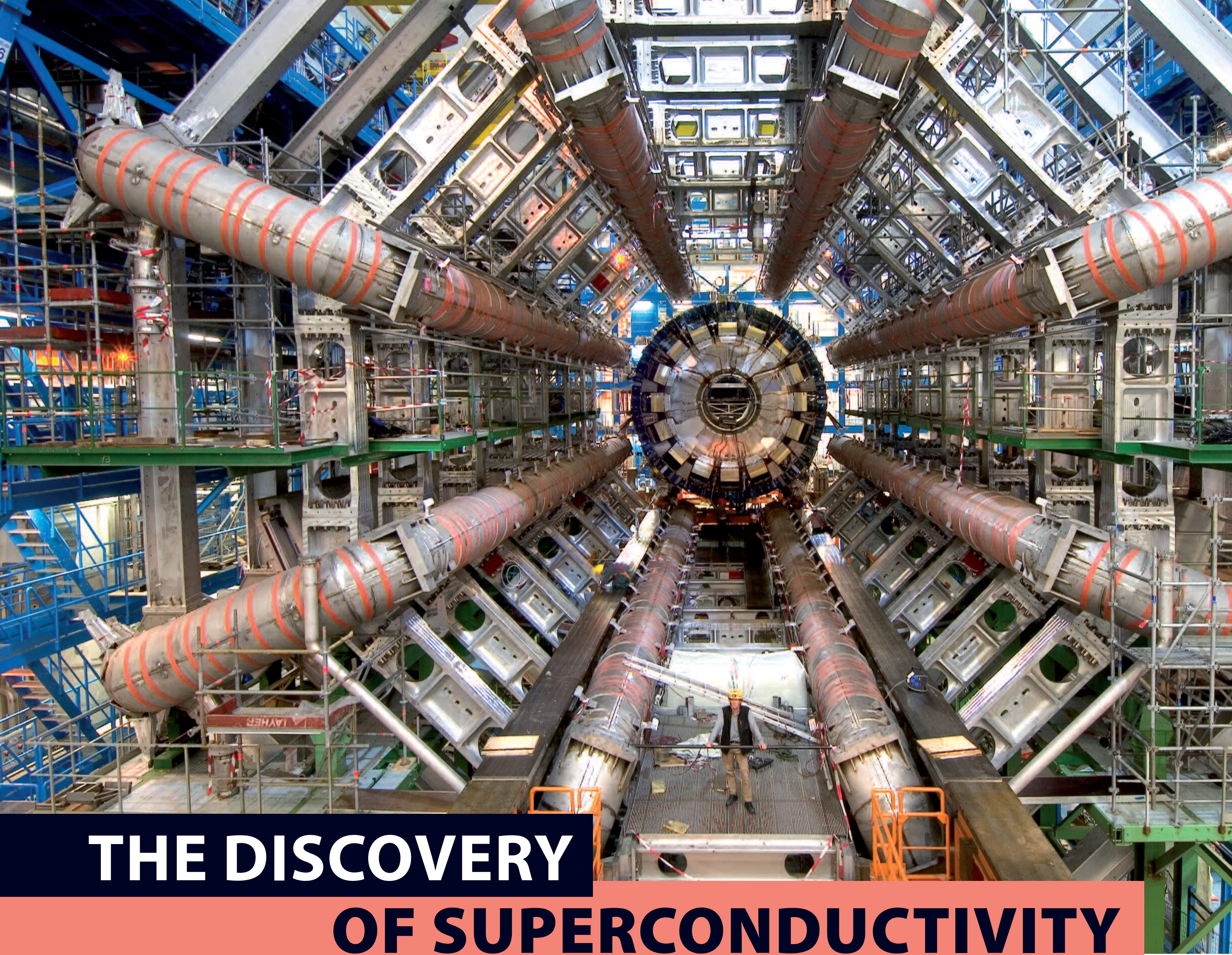
The wick is the heart of the candle. It not only melts the wax just below it, it also acts as a fuel pump by drawing up liquid wax by capillary action, thereby regulating the flame. And if we look carefully after lighting a candle, we notice that the flame is large at first, then gets smaller by lack of fuel, and only burns in its full glory once it manages to melt a layer of wax. The wick is usually made of braided cotton threads, treated with some inorganic compound to prevent afterglow once the flame is extinguished. Its construction has a decisive impact on the performance of the candle, including the stance of the wick and its ability to self trim. It may contain a zinc or tin core to help it stay upright when the surrounding wax liquefies.

The operation of the candle teaches us, in passing, that the heat of combustion is much greater than the heat of melting and the heat of vaporization combined. It is one of the elementary physics lessons hidden in a candle.

Obviously, the operation of the candle depends on natural convection to remove the combustion products and supply fresh oxygen. Indeed, in microgravity a lit candle burns only for a short while before extinguishing by lack of oxygen. Here is another physics lesson: diffusion at ambient pressure is a very slow process.

The flame itself represents a series of steps: vaporization of the wax, pyrolysis into gaseous hydrocarbon fragments and solid carbon particles ('soot') and, finally, burning of the carbon particles in the luminous cone which is the whole purpose of the candle to begin with. In case of incomplete combustion of these C-particles – for example, if there is lack of oxygen, or if a gust of wind decreases the flame's temperature to below 1000°C – the flame will emit soot and spoil the fun.

The temperature in the luminous cone is around 1200°C. Now it becomes clear just why a candle is such an inefficient light source. Not only is more than 80% of the heat convected up and away from the flame. The remaining 20% does not provide very efficient lighting either. If we assume that the burning carbon particles at 1200 °C behave like a Planck radiator, Wien's law tells us that its emission peak is at approximately 2 μm wavelength. Given the narrow eye sensitivity curve centered around 0.5 μm, the conclusion is inevitable. Candles provide interesting science, but hardly any light. ■



THE DISCOVERY OF SUPERCONDUCTIVITY

■ **Dirk van Delft** – Museum Boerhaave, PO Box 11280, 2301 EG Leiden, The Netherlands – dirkvandelft@museumboerhaave.nl
■ **Peter Kes** – Leiden Institute of Physics, PO Box 9504, 2300 RA Leiden, The Netherlands – kes@physics.leidenuniv.nl – DOI: 10.1051/epn/2011104

One hundred years ago, on April 8, 1911, Heike Kamerlingh Onnes and his staff at the Leiden cryogenic laboratory were the first to observe superconductivity [1]. In a frozen mercury wire, contained in seven U-shaped capillaries in series (see Fig. 1), electrical resistance suddenly seemed to vanish at 4.16 kelvin [2]. Short-circuit – an apparently obvious explanation – was excluded, but the question exactly what was going on would only receive a satisfactory answer at the fundamental level with the publication of the BCS theory in 1957 [3].

The discovery of superconductivity may have been accidental, but nonetheless the experiment was part of a carefully-considered research programme in Leiden. Studying the behaviour of the electrical resistance of metals (such as gold and platinum) at very low temperatures was interesting from both a practical and a theoretical point of view. Practical, because the fact that metal resistors were dependent on temperature made it possible to use them as (secondary) thermometers – thereby raising the possibility of a welcome addition to the (primary) gas thermometer which, although accurate, was cumbersome to use and slow in response. Theoretical, because Paul Drude had already applied the kinetic theory of gases to an electron gas in a metal in 1900, and on that basis had deduced the linear decrease in resistance with absolute temperature, while William Thomson (Lord Kelvin) had predicted one year later that at extremely low temperatures, the conducting electron would in fact become 'frozen solid' to the atoms, such that at absolute zero, resistance would become infinite [4].

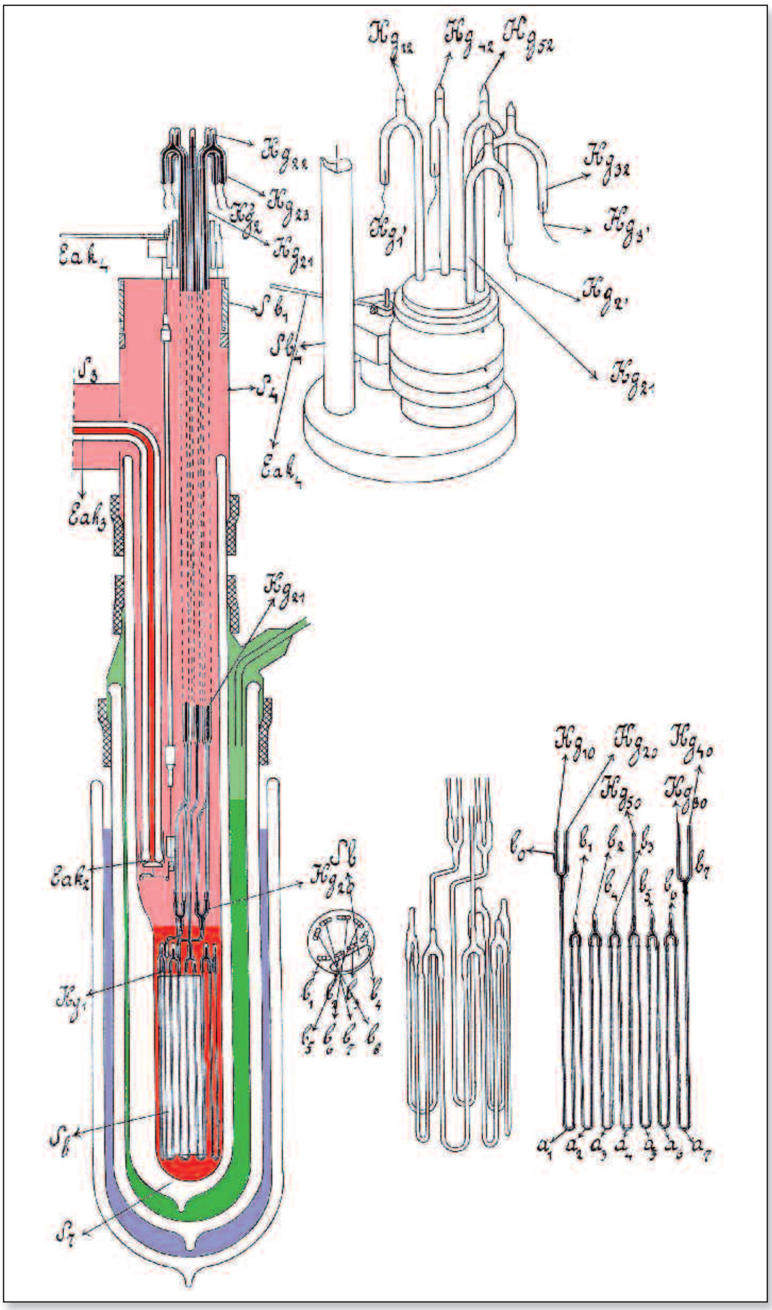
▲ The Atlas detector of the Large Hadron Collider at CERN, Geneva

Mercury

Using liquid hydrogen as a coolant, Jacob Clay and other students of Kamerlingh Onnes had succeeded in carrying out experiments down to 14 kelvin (the freezing point of hydrogen) at the Leiden Physics Laboratory, starting in 1906. It was noted during these experiments that, although the resistance of gold and platinum wire did fall with decreasing temperatures, at the same time it started to level out [5]. The successful liquefaction of helium on July 10, 1908 gave a massive boost to this research because at a stroke, temperatures as low as 1 kelvin had suddenly been made achievable [6]. The result of these new measurements was that at such very low temperatures, resistances reached a sort of residual value, that became lower the purer the platinum or gold could be made [7] (see Fig. 2). The expectation, therefore, was that with very pure metal, as absolute zero was approached, resistance would become equal to zero.

The logical next step was the choice of mercury since, via distillation, the metal could be made extremely pure. The capillary construction, a masterpiece of the Leiden-based glass blower Kesselring, was installed in the helium cryostat next to the liquefactor. The actual goal of the experiment was the test of the transfer system for liquid helium. During the decisive experiment on the 8th of April, 1911, Kamerlingh Onnes and Gerrit Jan Flim, head of the cryogenic laboratory and master instrument maker, were responsible for the cryogenic installations (see Fig. 3). Measuring the temperature (using a gas thermometer) was the task of Cornelis Dorsman, while the resistance of the mercury wire (and of gold) was determined via an electrical bridge circuit with a mirror galvanometer. The galvanometer was placed in a room at a safe distance from the throbbing pumps, on a vibration-proof column, and was monitored by Gilles Holst (who communicated via a speaking tube). The result of these experiments was that the mercury resistance did indeed fall to zero (see Figs. 4 and 5). However, the result was complicated by the occurrence of a transition temperature that could not be explained by theory [8].

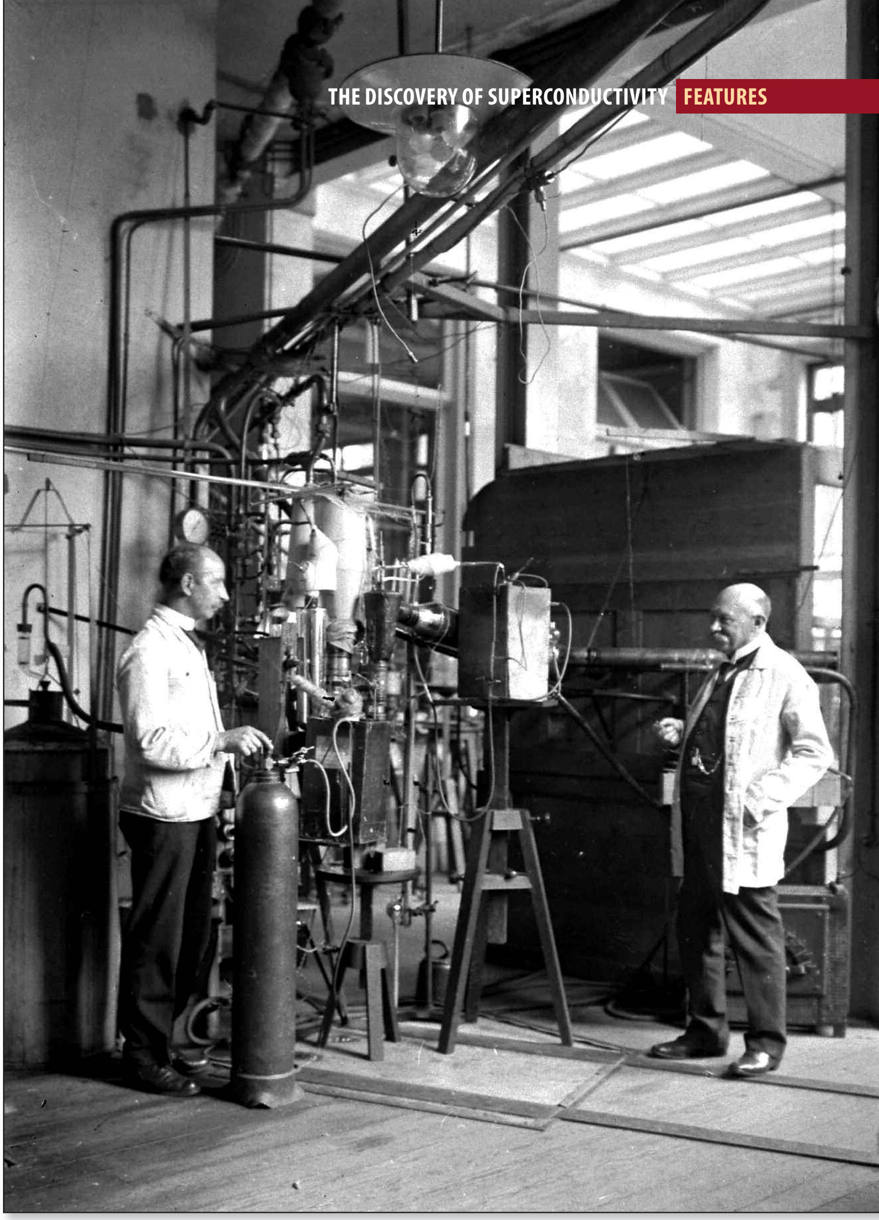
▼ **FIG. 1: Cryostat with mercury resistor and mercury leads for the 26 October 1911 experiment: seven U-shaped glass capillaries in series (inner diameter 0.07 mm), each with a mercury reservoir at the top and contact leads also made of glass capillaries filled with mercury. A similar design, but with copper contact leads, was used at the April 8 experiment. External contacts were made through Pt wires (denoted by Hg_{xx}) shown in the top right drawing. Colors have been added to indicate various cryogenic fluids: liquid air (purple), liquid and gaseous hydrogen (dark and light green), and liquid and gaseous helium (dark and light red).**



New superconductors

In December 1912, mercury as a superconductor was joined by tin and lead, metals with a transition temperature of 3.8 and 7.2 kelvin, respectively. From then on, there was no need to experiment with fragile mercury capillaries. Experiments could now be carried out with handy coils of wire. The wires were cut from a cylinder jacket in tin or lead, using a chisel, a method that clearly generated better results than the mechanical drawing of wires. Using sections of wire soldered together to form a total length of 1.75 metres, a coil consisting of some 300 windings, each with a cross-section of 1/70 mm^2, and insulated from one another with silk, was wound around a glass core (see Fig. 6). One major stumbling block was that the critical current (threshold current) in a tin or lead wire, above which the superconductivity disappeared, was far lower in a coil than in a straight wire. Whereas in a straight tin wire the threshold current was 8 ampère, in the case of the coil, it was just 1 ampère. A similar situation applied to lead. Initially, Kamerlingh Onnes attributed this effect to poor welding or other extrinsic effects [9].

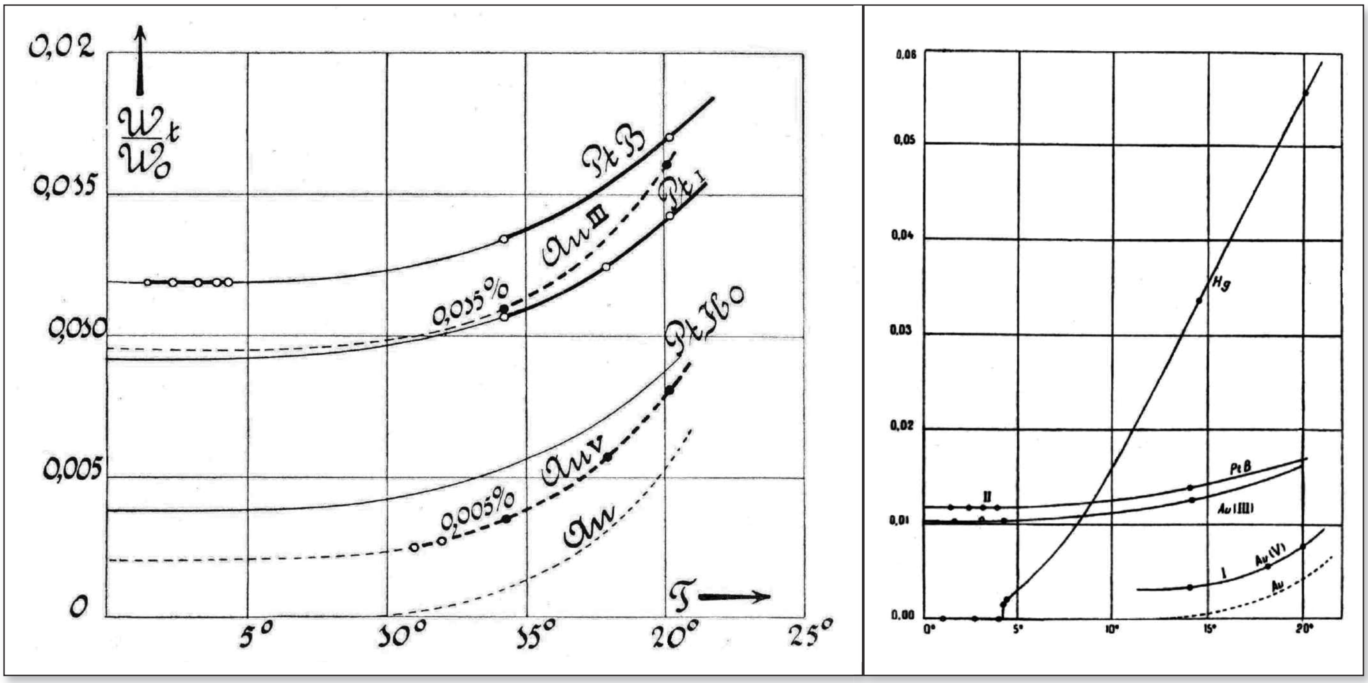
The wish was the father of the thought. The stakes were high: nothing less than a compact, powerful superconducting magnet. At the start of the century, Jean Perrin had already put forward the idea of a liquid-nitrogen-cooled magnet of copper wire, with a magnetic field of 100,000 gauss. Further quantitative analysis indicated that a giant magnet of this kind would require 100 kilowatt of power. The timely discharge of the heat would require at least 1500 litres of liquid air per hour, making this 'dream magnet' as expensive to build as a battle cruiser. The situation with superconductivity was different. At the third International Congress of Refrigeration in Chicago, in the autumn of 1913, Kamerlingh Onnes once again raised the issue of the super magnet. 'The solution to the problem of obtaining a field of 100,000 gauss could be obtained by a coil of, say, 30 centimetres in diameter, and the cooling with helium would require a plant which could be realized in Leiden with a relatively modest financial support', he wrote in his summary of the cryogenic work in Leiden. 'Since we may confidently expect an accelerated development of experimental science, this future ought not to be far away' [10]. In Chicago, George Claude, founder of Air Liquide, promptly took the initiative of providing financial

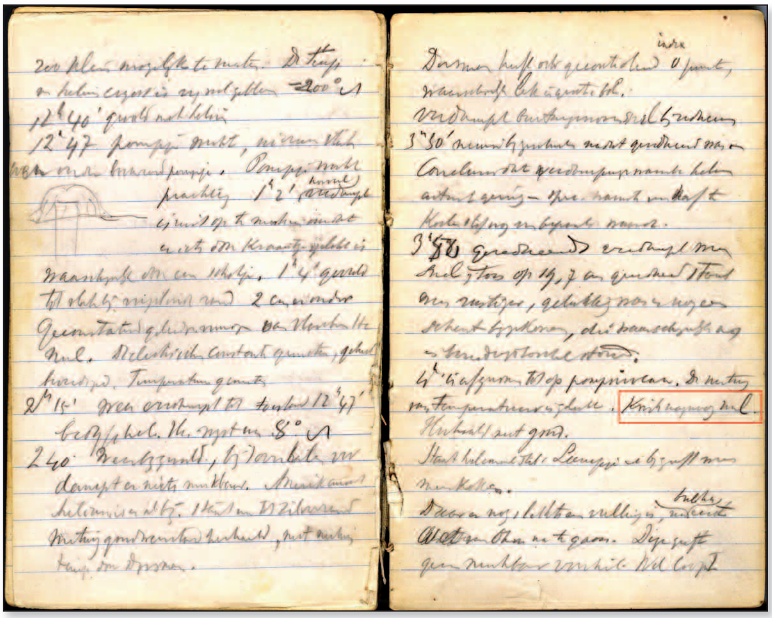


▲ **FIG. 3:** Gerrit Jan Flim (left), head of the Leiden cryogenic laboratory, and Heike Kamerlingh Onnes at the helium liquefier. Ca. 1920.

> "The capillary construction was a masterpiece of the Leiden-based glass blower Oskar Kesselring"

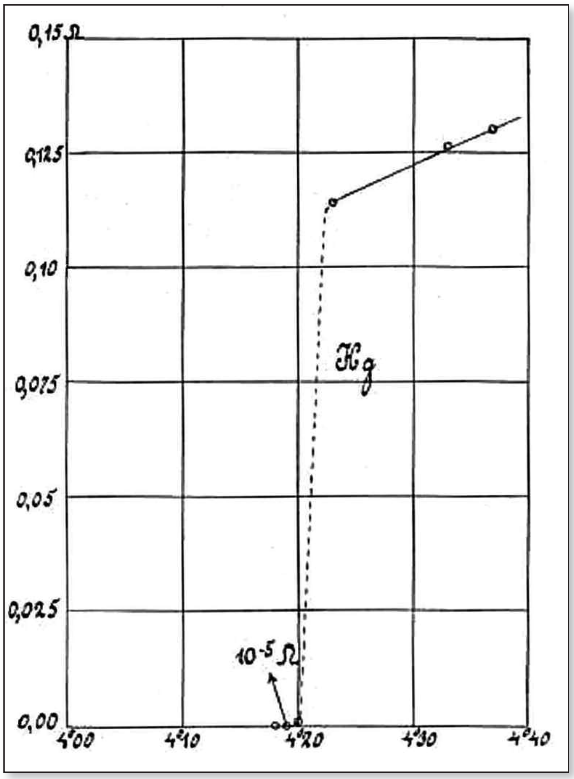
▼ **FIG. 2:** Resistance ratios of some metals versus temperature *T* in kelvin. Left-hand panel (a): Several platinum and gold resistors of various purities measured at different hydrogen temperatures. Pt-B was the first resistor ever to be cooled to helium temperatures in the experiment of 2 December 1910. The constant resistance below 4.3 K contradicted Kelvin's model for conductance; the electrons did not freeze onto the ion lattice at absolute zero. The remaining resistance was due to scattering of the electrons on impurities. By making the metal wires purer, both chemically and physically (by annealing out the lattice disorder), the resistance was shifted downwards by a constant value, demonstrating that Matthiessen's rule is valid down to the lowest temperatures. Right-hand panel (b): The resistance ratio of Pt and Au compared to that of mercury (Hg, steep curve). Here, I denotes the temperature range of liquid hydrogen, II that of liquid helium.





▲ **FIG. 4:** A crucial page from the entry for 8 April 1911 in Kamerlingh Onnes's notebook. The highlighted sentence Kwik nagenoeg nul means "Mercury['s resistance is] practically zero [at 3.0 K]" announcing the first observation of superconductivity. On the page left the sketch of the functioning stirrer is seen. (Archive of the Boerhaave Museum, Leiden).

► support for Kamerlingh Onnes' superconducting magnet project to the tune of 100,000 francs (the outbreak of World War One threw a spanner in the works). Unfortunately, the disastrous effect of a magnetic field on superconductivity was rapidly revealed. On a lead coil at 4.25 kelvin, superconductivity disappeared when a field of just 600 gauss was applied [11]. As a consequence of this magnetically induced return of the resistance,



▶ **FIG. 5:** Historic plot of resistance (Ω) versus temperature (K) for mercury from the 26 October 1911 experiment showing the superconducting transition at 4.20 K. Within 0.01 K, the resistance jumps from unmeasurably small (less than 10^{-5} Ω) to 0.1 Ω.

the superconducting variant of Perrin's dream was totally shattered. It was not until the nineteen sixties that the powerful superconducting magnet was finally introduced, thanks to niobium titanium wire. This is a conventional superconducting material with a high threshold field, a large current density, and a transition temperature (T_c) of 9 kelvin. MRI scanners and deflection magnets in particle accelerators still make use of magnets of this kind. All we are now waiting for is suitably high T_c superconductors from which wires can be drawn in a technically manageable way, thereby eradicating the need for cooling by liquid helium.

Applications

In fact, such wires already exist, but they are still relatively expensive and therefore they are only used in applications where best performance prevails over costs. For instance, the current leads from the room-temperature power supplies to the deflection magnets of the LHC at CERN are made of BiSrCaCuO. High T_c cables for electric power transport operating at liquid nitrogen temperature are currently being tested in several pilot projects. When successful, those cables will replace the high-voltage power lines of copper in urban areas and perhaps, in the near future, a world-wide net of such high T_c power lines will transport energy from durable energy power plants to big consumer concentrations.

The present situation is that superconductivity is mainly utilized for medical diagnostics (MRI systems) and for scientific purposes (particle accelerators and detectors, high-field NMR). These applications are based on the very high current densities without losses in magnetic fields of over 20 tesla which have been obtained in materials such as Nb-Ti and Nb_3Sn. This property makes these materials very suitable for the construction of a large variety of superconducting magnets. There is also an important market for low current superconducting electronics, predominantly based on the tunnelling of Cooper pairs (the Josephson effect , predicted and first observed in 1962) and the quantization of magnetic flux combined in Superconducting Quantum Interference Devices (SQUIDs). Very sensitive measuring equipment based on SQUIDs can be found nowadays in almost every solid state or materials physics laboratory.

One may thus conclude that today's utilization of superconductors has been made possible by the great discoveries and developments in the fifties and sixties of the last century. Just to name a few: the discovery of the isotope effect, the purity dependence of the penetration depth, the phenomenological Ginzburg-Landau theory, the Abrikosov theory of type II superconductors, the microscopic BCS theory and its extensions by Gor'kov, Bogoliubov, De Gennes, Anderson and Eliashberg, electron-phonon spectroscopy, the observation of flux quantisation, the prediction and discovery of the Josephson effect, the observation of flux line lattices, and so on [12, 13]. The latter demonstrated the existence of flux lines containing a single quantum of magnetic flux, as predicted by Abrikosov. Without flux lines and the pinning of flux lines, high critical currents would not be possible, and consequently high current applications would not exist. One can safely state therefore that the application of superconductors relies on superconductivity being a macroscopic quantum phenomenon. And one can also state that conventional superconductors are completely understood. A nice example is the recently discovered "high-temperature" MgB_2 ($T_c \approx 40$ K). Within a year of its discovery the conventional BCS-Eliashberg framework could tell us why this simple metal has such a surprisingly high critical temperature.

The "true" high-temperature superconductors are a totally different story. Life changed with the discovery of superconductivity in what essentially are doped insulators. As Beasley expresses it in his contribution to [13]: "Historically [...] there are clearly two epochs: *From Onnes to Bednorz and Müller*, and *After Bednorz and Müller*". The understanding of those strongly correlated, quasi two-dimensional electron systems like the doped cuprates or the recently discovered doped Fe pnictides is still evolving. It is an extremely exciting field with many deep questions that still wait for an answer. A nice and profound review of the progress made in the last two decades is given in [14].

From March 1, 2011 to April 1, 2012, Museum Boerhaave in Leiden will host the special exhibition 'Mercury practically zero. A hundred years of superconductivity'. See www.museumboerhaave.nl. ■

About the authors

Dirk van Delft is director of Museum Boerhaave, the Dutch museum for the history of science and medicine, and extraordinary professor 'Heritage of the Sciences' at Leiden University. In 2007 he published *Freezing Physics. Heike Kamerlingh Onnes and the Quest for Cold* (Edita, Amsterdam).

Peter Kes is emeritus professor in experimental physics at the Kamerlingh Onnes Laboratory, Leiden Institute of Physics of Leiden University. In the fall of 2009 he retraced the notebooks of Kamerlingh Onnes describing the first resistance measurements on mercury.

▲ **FIG. 6:** Coil of lead wire (viewed along coil axis), used in 1912 by Kamerlingh Onnes and his co-workers and now in Museum Boerhaave.

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[5] H. Kamerlingh Onnes and J. Clay, *KNAW Proceedings* **10** I (1907), 207. *Comm.* **99c**.

[6] H. Kamerlingh Onnes, *KNAW Proceedings* **11** (1909),168. *Comm.* **108**.

[7] H. Kamerlingh Onnes, *KNAW Proceedings* **13** (1911), 1093. *Comm.* **119**.

[8] It becomes clear from this presentation of the course of events during the experiment, that the regularly recurring claim that Holst in fact discovered superconductivity is entirely unfounded. Holst, in 1914 appointed as first director at Philips Research, in fact never claimed that position.

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[10] H. Kamerlingh Onnes, *Comm.* Supplement **34a**.

[11] See note 9.

[12] H. Kamerlingh Onnes *Symposium on the Origins of Applied Superconductivity – 75th Anniversary of the Discovery of Superconductivity* at the 1986 APPLIED SUPERCONDUCTIVITY CONFERENCE, September 28-October 3, 1986, Baltimore, Maryland, IEEE Transactions on Magnetics, MAG-23 (1987) 354.

[13] A book project "100 Years of Superconductivity" is underway with many (personal) scientific contributions which both give an account of the historic developments in the passed 100 years, but also the present view on the perspectives of superconductivity and its applications. See www.eucas2011.org the link "Book Project" for actual information.

[14] 'J. Zaanen, 'A modern, but way too short history of the theory of superconductivity at a high temperature', to appear in [13]. See also http://arxiv.org/abs/1012.5461

■ Ewine F. van Dishoeck - Leiden Observatory, Leiden University,
P.O. Box 9513, 2300 RA Leiden,The Netherlands - ewine@strw.leidenuniv.nl - DOI: 10.1051/epn/2011105

WATER IN SPACE

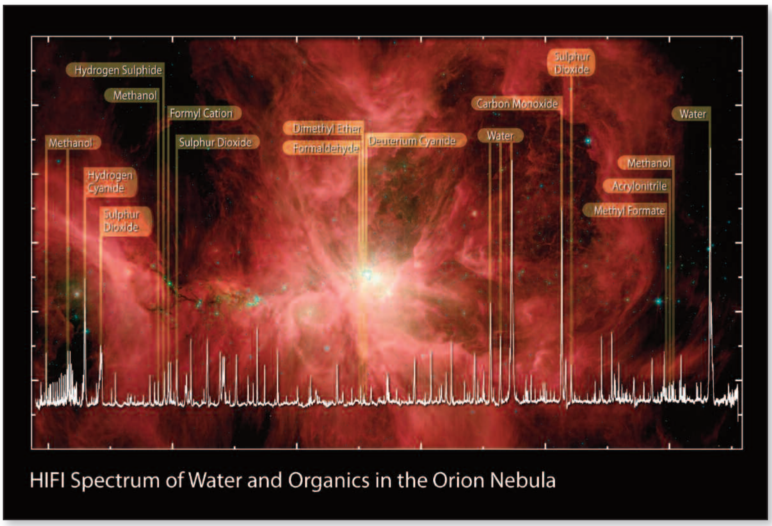
Water is a key molecule in the cosmos, from distant galaxies and star-forming regions in the Milky Way to the Solar System and our own blue planet. The Herschel Space Observatory, launched in 2009 by the European Space Agency, provides astronomers with a unique opportunity to observe water throughout the Universe unhampered by the Earth's moist atmosphere. Initial results show that water emission elucidates key episodes in the process of stellar birth.

The space between the stars forms a gigantic physical-chemical laboratory with conditions that cannot be readily simulated in an experiment on Earth. It is filled with a very dilute gas, of which the denser concentrations are called 'interstellar clouds'. These clouds are present throughout our galaxy and can sometimes be seen as dark regions on optical images of the sky (Figure 1). They appear dark against a light background because of the presence of small solid particles which absorb and scatter the visible radiation. New generations of stars like our Sun and planets like Jupiter or Earth are born inside these dense clouds [1].

With typical densities of only 10^4 particles per cm^3 and temperatures down to 10 K, traditional chemistry would predict that virtually no molecules can form under these extremely low temperature and density conditions. Yet it has become clear over the last 40 years that interstellar space has a very rich chemistry, with more than 150 different molecular species detected (not counting isotopes) (Figure 2). Main questions in the field of astrochemistry include: how are these molecules produced? How far does this chemical complexity go? Can they become part of new planetary systems where they may form the building blocks for life?

Water is undoubtedly one of the most important of molecules found in space. As a dominant form of oxygen, the most abundant element in the universe after H and He, it controls the chemistry of many other species, whether in gaseous or solid phase. It is a unique diagnostic of the warmer gas and the energetic processes that take place close to forming stars, as will be shown below. Water is also partly responsible for keeping the gas at low temperatures because the cloud cools whenever line radiation escapes. These low temperatures, in turn, allow clouds to collapse to form stars. In cold regions, water is primarily in solid form, and its presence as an ice may help the ►

▲ **FIG. 1:** **Hubble Space Telescope optical image of the Carina nebula. The dark regions are dusty clouds which contain a wealth of molecules and in which new stars are born. (Credit: NASA/ESA)**



▲ **FIG. 2:** **HIFI spectrum of the Orion nebula around 1 THz (300 μm wavelength) showing lines of water and complex organic molecules, superimposed on a Spitzer Space Telescope mid-infrared image of Orion [2]. This figure illustrates the spectral richness of regions of star and planet formation. (Credit: ESA, HEXOS and the HIFI consortium; Background image: NASA/JPL-Caltech)**

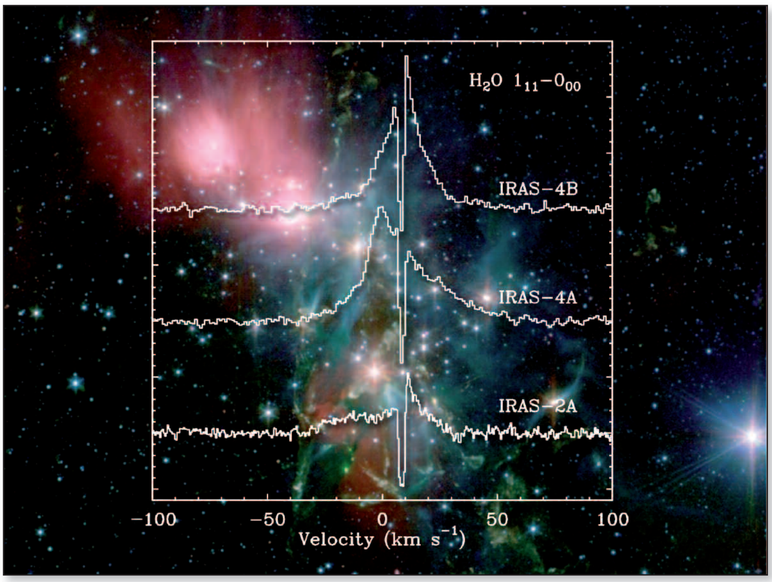
► coagulation process of dust grains that ultimately produces planets. Asteroids and comets containing ice have likely delivered most of the water to our oceans on Earth, where water is directly associated with the emergence of life. The distribution of water vapor and ice during the entire star and planet formation phase is therefore a fundamental process relevant to our own origins.

How to observe water?

Most interstellar molecules are observed through their pure rotational lines at millimeter wavelengths, excited by collisions with H_2. Radio telescopes situated at high dry sites on Earth operating at wavelengths around 1 millimeter can readily detect many species. However, because of its high abundance in our own atmosphere, lines from interstellar water generally do not reach the Earth's surface. Thus, space observatories equipped with state-of-the-art instruments are essential to detect the bulk of the interstellar water.

On May 14 2009, the European Space Agency successfully launched the long-awaited Herschel Space Observatory from French Guyana (see box). Herschel is the largest space telescope ever built, with a single mirror measuring 3.5m in diameter, even exceeding the Hubble Space Telescope mirror in size. Its three instruments provide imaging and spectroscopic capabilities in the 50-500 μm wavelength range, one of the last unexplored regions of the electromagnetic spectrum. This wavelength range is particularly rich in rotational transitions of H_2O and related hydrides such as OH. Indeed, observing water in space was one of the main drivers for the design of Herschel.

▼ **FIG. 3:** **HIFI spectra of the p-H_2O ground-state 1_{11}-0_{00} line at 1.1 THz (270 μm) toward three low-mass protostars in the NGC 1333 star-forming region [5]. (Credit: ESA, WISH and the HIFI consortium; Background Spitzer image: NASA/JPL-Caltech)**



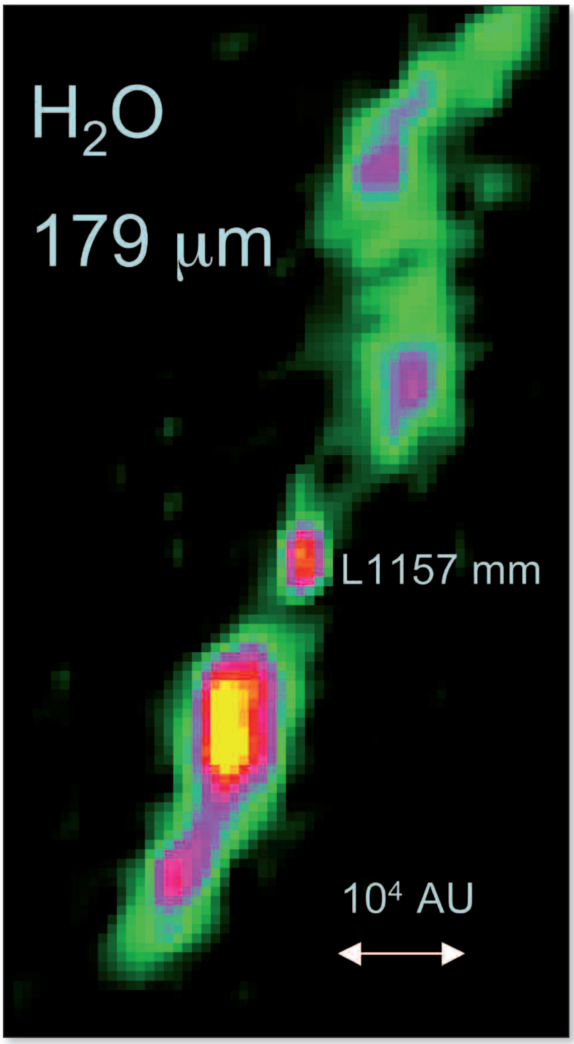
A WISH comes true

The Heterodyne Instrument for the Far-Infrared (HIFI) is one of the three instruments onboard Herschel. It was built by an international consortium under the leadership of the Netherlands Institute for Space Research (SRON) [3], and its very high spectral resolution is particularly well suited for studying water vapour. As a reward for its investments, the HIFI consortium was awarded guaranteed observing time to carry out a number of key programs. The largest of these programs is 'Water In Star-forming regions with Herschel' (WISH), which uses 425 hr to observe ~80 sources throughout the galaxy which are currently in the process of forming stars [4]. A wide range of stellar masses and luminosities are covered, from the lowest to the highest mass protostars, and a large range of evolutionary stages, from the first stages represented by dense cores that have not yet collapsed to form stars to the last stages where the cloud surrounding the young star has been dissipated.

Various lines of water originating from a range of energy levels are targeted to probe both cold and warm water. In addition, deep integrations on lines from $^{18}OH_2$ and $^{17}OH_2$ are performed. Because their lower abundances by factors of ~500 and ~2500, respectively, the lines from these isotopologues suffer less saturation and are thus easier to analyze than those of $^{16}OH_2$. This plethora of water lines provides anything but redundant information: it actually helps to overcome one of the natural drawbacks of astronomical observations, which yield only two-dimensional images due to the projection on the sky. Since each line arises in a slightly different volume in an interstellar cloud, all the information put together provides a three-dimensional view. Thus, the HIFI data provide a natural tomography of these regions.

Figure 3 presents recent HIFI spectra of H_2O in three low-mass star-forming regions [5].

The quality of the data is excellent and the line profiles are fully resolved (resolution 0.07 km/s at 1 THz). The profiles are surprisingly complex, revealing both broad emission and narrow absorption components. The narrow absorption lines (few km/s width) originate in quiescent cold gas in the outer envelope surrounding the protostar. The broad lines (widths up to 50 km/s) arise in fast-moving gas caused by shocks associated with the jets and winds from the young stars.
These characteristics are seen for all lines, arising from energy levels up to several hundred K above ground, and for all isotopologues. Thus, it can be concluded immediately that the bulk of the water emission originates from hot shocked gas rather than cold quiescent material. A quantitative analysis of the data shows that the abundance of water with respect to the basic molecule H_2 is about 10^{-4} - 10^{-5} in the hot gas, but only 10^{-8}-10^{-9} for the cold gas. Since the overall abundance of oxygen with respect to hydrogen is about 3.10^{-4}, this means that most of the available oxygen is driven into water in hot gas, whereas most water is frozen out on grains in cold clouds.
The importance of water as a physical diagnostic stems precisely from these gas phase abundance variations by an order of magnitude between warm and cold regions. Water vapour acts like a 'switch' that turns on whenever energy is deposited in molecular clouds in the processes accompanying stellar birth. This fact is beautifully illustrated in the first water map of a forming star (Figure 4): The water emission 'lights up' close to the protostar and in hot spots where the jet interacts with the surrounding cloud [6].



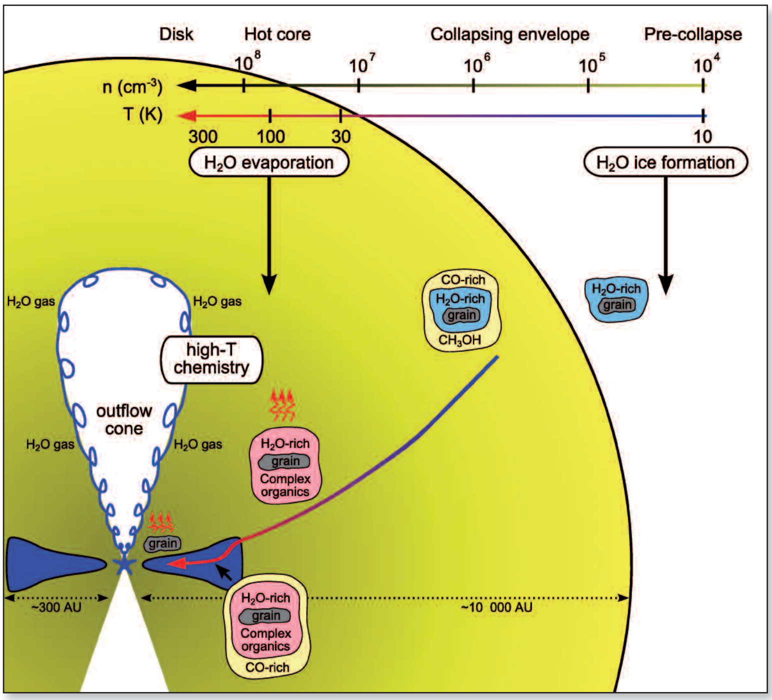
◄ **FIG. 4:** PACS image of the water 179 μm (1.7 THz) line toward L 1157 (a low-mass protostar comparable to our Sun when it was a toddler), lighting up the two-sided outflow of gas [6]. The scale is indicated in Astronomical Units, with 1 AU = distance Sun-Earth = $1.5\ 10^{13}$ cm.

Water formation routes

How is this water produced and why are its abundance variations so large? Under interstellar conditions water gas is mainly formed through reactions between ions and neutral species, starting with the $O + H_3^+ \rightarrow OH^+ + H_2$ reaction. However, in cold and dense clouds H_2O is formed more efficiently on the small solid particles (0.1 μm-sized silicates and carbonaceous material) which act as a sink on which gaseous species can freeze out (Figure 5). Although the details how O and H combine on a solid surface to form H_2O are not yet fully understood, there is ample observational evidence that the H_2O ice abundances in protostellar envelopes can be as high as 10^{-4}, locking up most of the available oxygen.
Once the protostars turn on, they heat the surrounding material and the grain temperature can rise above 100 K. As a result, all H_2O ice thermally desorbs, just like the ice in a comet evaporates when its nucleus is heated as it passes close to the Sun. At even higher temperatures, above 230 K, the gas-phase reactions of $O + H_2 \rightarrow OH + H$ and $OH + H_2 \rightarrow H_2O + H$ become significant. The combination of these processes explains why hot gas is literally 'steaming'.

Herschel Space Observatory

Herschel is a 3.5m passively cooled telescope built and launched by the European Space Agency (ESA)
(Figure 7). It contains three instruments built by large international consortia of institutes, housed in a superfluid helium cryostat which provides an operational lifetime for astronomical observations of about 3 yr. From conception to launch, the building of Herschel and its instruments took about 30 years. Herschel is currently in orbit some 1.5 million km from Earth.
The Heterodyne Instrument for the Far Infrared (HIFI) is a very high resolution heterodyne spectrometer covering the 490-1250 GHz (600-240 μm; 16-42 cm^{-1}) and 1410-1910 GHz (210-157 μm; 47-64 cm^{-1}) bands. HIFI observes a single pixel on the sky at a time.
The Photodetector Array Camera and Spectrometer (PACS) consists of a camera and a medium resolution imaging spectrometer for wavelengths in the range 55-210 μm (180-47 cm^{-1}). The spectrometer obtains spectra simultaneously over a limited wavelength range at each pixel of a 5x5 array. The Spectral and Photometric Imaging REceiver (SPIRE) is a camera and a low resolution Fourier Transform Spectrometer complementing PACS for wavelengths in the range 194-672 μm (51-15 cm^{-1}).

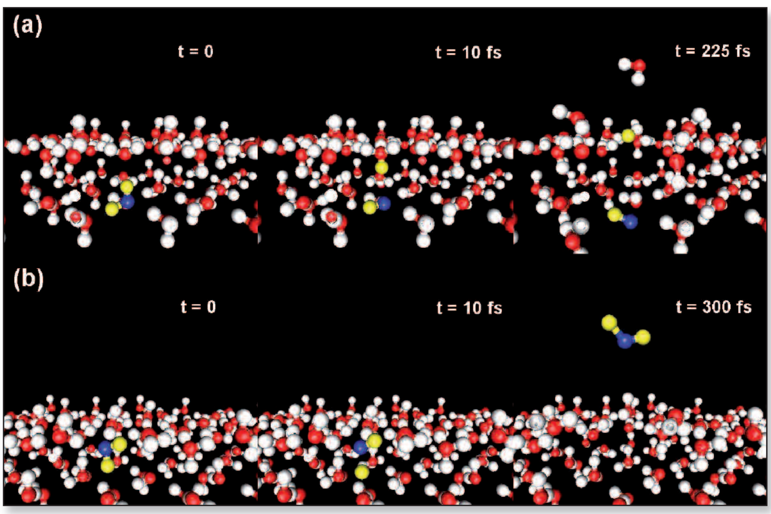


▲ FIG. 5: Evolution of water from a cold core through a collapsing envelope into the planet-forming zones of disks. Water is formed primarily on the surfaces of sub-micron-sized grains (not drawn to scale) and can evaporate back in the gas in the warm regions close to the protostar. Water is also produced in the shocks associated with the outflows [1,4]. Most water is thought to enter the disk as ice.

Surprise: ionized water

An early surprise from Herschel is the detection of widespread ionized water, H_2O^+, in a variety of galactic and even extragalactic sources. Although this ion was predicted to be detectable in regions exposed to energetic radiation, its ubiquitous presence was unexpected since H_2O^+ is readily transformed into H_3O^+ through reactions with H_2. Its relatively high abundance implies that the radiation driving its formation is even more widespread throughout interstellar clouds than thought before.

▲ FIG. 6: Snapshots of trajectories of mechanisms of H_2O desorption for a crystalline ice model exposed to UV radiation. The blue + yellow O and H atoms denote the water molecule that is (randomly) chosen to bephotodissociated by UV radiation at t=0. Top: kick-out mechanism; Bottom: H + OH recombine and desorb [11].



Molecular physics and water

To use water as a physical and chemical probe of star-forming regions, many basic molecular processes need to be understood. Often, these astronomical needs drive further molecular physics studies, thus leading to a fruitful synergy between astronomy and physics. A prime example of this interaction are the cross sections for collisions of H_2O with the main collision partner in clouds, H_2, which are needed to translate the observed line intensities into abundances. Discrepancies between experiment and theory have recently been resolved thanks to intense discussions in the physics community, allowing astronomers to quantitatively analyze their data [8].

Accurate line frequencies are crucial for identification of new molecules in space. Those for water are well known to better than 1 part in 10^7, but frequencies of ions such as H_2O^+ and OH^+ are still uncertain by tens of MHz [7]. Since (hyper)fine-structure can aid in making a firm identification, astronomical spectroscopy is in this case ahead of laboratory work.

Photodissociation plays a key role in the destruction of water. The absorption of a UV photon by gaseous H_2O leads directly to dissociation into OH and H. The interstellar radiation field contains photons with energies up to 13.6 eV (the Lyman limit of the H atom). Very little is known, however, what happens inside a water ice exposed to this UV radiation. Our group in Leiden has for the first time simulated outcomes of this process in the computer [9]. In most cases, H escapes from the ice, but about 0.05% of the dissociations result in desorption of a H_2O molecule, either following reformation of H + OH or through a process in which the energetic H 'kicks-out' a neighboring H_2O molecule (Figure 6). These results agree well with recent experiments [10]. Astronomically, ice photodesorption turns out to be a key process in explaining the presence of a low abundance of molecules in cold gas at temperatures where they should all have been frozen out onto the dust grains.

The formation of water ice itself from O and H atoms was postulated 25 years ago but never tested in the laboratory until recently, when a number of groups started building ultra-high-vacuum surface science experiments dedicated to simulating the interstellar conditions. Key steps in the ice formation process have now been elucidated in this exciting new field [11].

Outlook

Although less than 10% of the WISH data have been analyzed, the observations obtained so far indicate that Herschel will indeed be able to follow the water trail from the most diffuse gas to dense collapsing clouds, and eventually comets and planets in our own

▲ **FIG. 7:** Artist impression of the Herschel Space Observatory superimposed on an image of the Rosette nebula taken by Herschel. (Credit: ESA)

Solar system (Figure 5). Initial surprises include the absence of gaseous water in cold clouds at levels even lower than predicted, the dominance of shocks in controlling the bright water emission from protostars, and the ubiquitous presence of some ions. In turn, the Herschel data raise new questions on molecular spectroscopy, collision cross sections and basic processes involving water and related species, both in the gas and in the solid state. Herschel will surely strengthen the stimulating interactions between astronomy and physics in the coming years. It is fascinating to realize that the water molecules that constitute the bulk of our bodies and that we drink every day were produced on the dust grains in the cloud from which our Solar system formed some 4.5 billion years ago. ■

About the author

E.F. van Dishoeck studied chemistry in Leiden (the Netherlands), obtained her PhD in astronomy in Leiden, was postdoc and (visiting) professor at Harvard, Princeton and Caltech (all USA), before moving back to Leiden in 1990, where she holds a professorship in molecular astrophysics. She is also an external scientific member at the Max Planck Institute for Extraterrestrial Physics in Garching (Germany). She first became involved in Herschel in 1982 and has actively promoted Herschel and HIFI over the last 30 years. She is the principal investigator of the WISH key program.

Acknowledgments

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Further information about WISH, including outreach and educational material: www.strw.leidenuniv.nl/WISH. Further information about Herschel: http://herschel.esac.esa.int

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