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THE MAGAZINE OF THE EUROPEAN PHYSICAL SOCIETY

First direct detection of gravitational waves

PT symmetry in quantum physics

EPL for the IYL 2015

Delicious ice cream: why does salt thaw ice?

Fascinating optics in a glass of water

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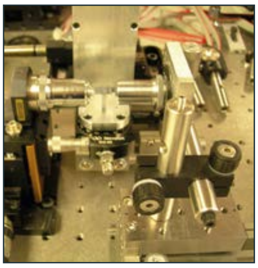
Cover picture: Artist's impression of gravitational waves generated by a binary black hole system. © iStockPhoto. See "First direct detection of gravitational waves" p.09.



▲ PAGE 17

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▲ PAGE 21

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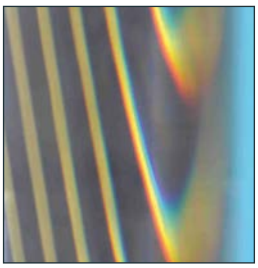


▲ PAGE 28

Fascinating optics in a glass of water

[EDITORIAL]

Big challenges and international collaboration

We frequently find news about global problems, affecting in a bigger or lesser way the welfare of humankind. Solving these problems defies the capabilities of isolated institutions and countries. The solutions require international or global collaborations, including many scientists and institutions.

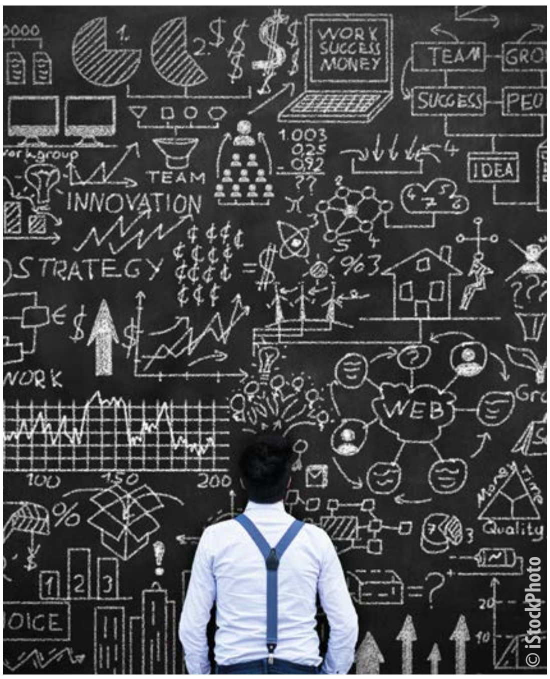
We know, by experience, that this is not easy to achieve, when trying to satisfy the interests of all parties involved in the collaboration.

But we know also that big international scientific collaborations are working successfully to solve problems beyond the resources of any individual partner. These collaborations can be successful by a judicious organization and distribution of responsibilities and tasks among the different partners, using their individual capacities. These synergies foster not only the common project but also favour local development of the different partners. Technological development, construction, operation and scientific analysis of data of such projects often take decades and involve large amounts of human and financial resources. Physics, in particular, can exhibit many examples of international collaboration.

The IYL2015 has been officially closed in the past days. This event has been a showcase of many different activities all over the world. It can exhibit the organization of more than 5,000 activities, including scientific conferences, art projects, exhibitions, active learning workshops, festivals and many more, reaching millions of people. The international impact was also shown by the many partners involved in the organization of the IYL 2015. IYL2015 is closed but not dead, and its spirit is very much alive in all the events and activities going on, thanks to the momentum generated in these years.

Recently the first direct detection of gravitational waves, predicted by Albert Einstein just over 100 years ago, has been confirmed officially. This has been done by measuring the tiny disturbances in space and time produced when the waves pass through the earth. These waves, after a 1.3 billion years journey, brought the news that a massive black hole was born as a consequence of the merger of two smaller black holes. This achievement has been possible after many years of work by scientists and engineers in different countries and different continents. Just think of the problems solved to detect these minute disturbances in the space-time fabric.

This is not simply another validation of the Theory of General Relativity of Albert Einstein, but the outcome of impressive work in theoretical and applied physics, engineering, instrumentation and international collaboration.



This is the common language of science, together with the will to obtain new insight and widen the horizons of the scientific knowledge.

Climate change and renewable energy are subjects having big influences in our society. Much effort is being devoted to reduce carbon emissions and increase renewable energy to provide electricity supply. These subjects cannot be addressed by different scientific disciplines separately. Multidisciplinary collaborations are active in these and related subjects, involving many scientists collaborating all over the world.

These international partnerships are formed by individuals of different countries, having different languages, education and cultures. These backgrounds could act against the collaboration, but there is a more fundamental glue. This is the common language of science, together with the will to obtain new insight and widen the horizons of the scientific knowledge. These are the strong links of the partnership.

These collaborations show what can be done by different countries working together with a common goal. They show also that these partnerships are not about obtaining economic or political benefits, although they can legitimately be reaped. They are also an example of how the combination of basic and applied research can increase the scientific knowledge and generate material benefits. ■

■ **Victor R. Velasco**
EPN Editor

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EPS HISTORIC SITES

Ernst Mach house

Ovocny trh 7, Prague, Czech Republic

The centenary of Ernst Mach's death is commemorated this year. Time passes quickly. Some five years ago, in anticipation of the anniversary, the Czech physical society proposed to mark the building where Ernst Mach worked in Prague as an EPS historic site. Once EPS supported the idea, administrative and design planning for the plaque started.

Indeed, the historical building, the former Institute of Physics, is located in the UNESCO protected Old Town of Prague, where patience and attention to details is required. Fortunately enough, the building is still in the ownership of the Charles University, which - after initial detailed scrutiny of the project - helped the cause considerably.

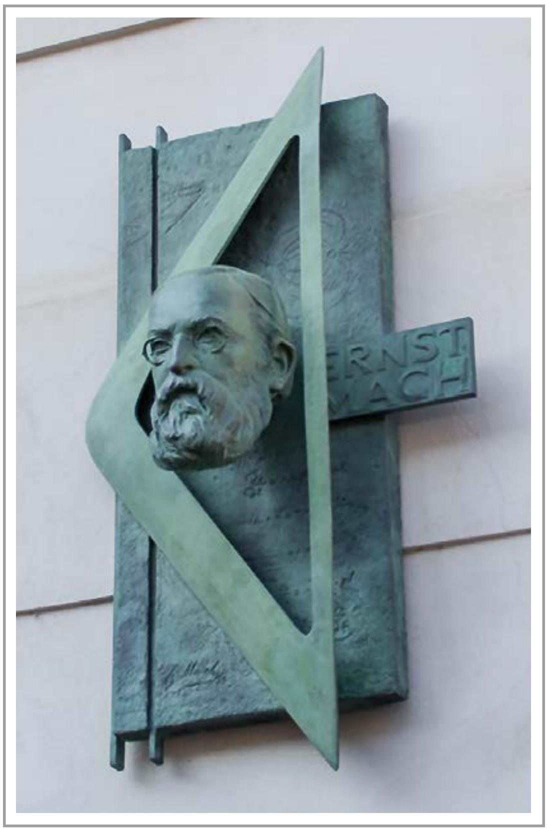
Eventually, the new EPS Historic Site was ready for the ceremony of unveiling the commemorative plaque just on time. It took place on the 18th of February 2016, when about 50 guests arrived to share the solemn moments including President of the EPS Christophe Rossel, President of the Czech Academy of Sciences Jiří Drahoš, Vice-mayor of the City of Prague Eva Kislingerová, the Ambassador of Austria Alexander Grubmayr, vice-rectors of the Charles University Jan Hála and Jan Royt, President of the Austrian Physical

Society Eberhard Widmann, President of the Slovak Physical Society Julius Cirák, Director of the Institute Vienna Circle Friedrich Stadler as well as Peter Schuster from the EPS History of Physics group.

After the unveiling act, the author of the sculpture Mr Jakub Vlček explained the idea behind the plaque. It has been inspired by one of the first photographs of the shock wave, the well-known key experimental result of Ernst Mach. The accompanying plate gives the following information in three languages (Czech, English and German): *Physicist and philosopher Ernst Mach worked in this building from 1867 to 1879 as Director of the University Physics Institute. Here he started his groundbreaking research on shock waves (the Mach number). His criticism of Newtonian mechanics deeply influenced Albert Einstein (Mach's principle).*

In total, Ernst Mach spent in Prague 28 years, *i.e.* the major part of his professional life. He served as dean of the Faculty of philosophy and also as rector of the University. From 1879 Mach moved to the brand new location of the University in Viničná Street, the very building where Albert Einstein would later stay (1911-1912). Ernst Mach left Prague in 1895, when he accepted a professorship in Vienna.

After the ceremony, work and life of Ernst Mach were detailed in a seminar organised by the Czech physical society and hosted by the Charles University in the nearby premises of the rectorate. The seminar started with presentation by the President of EPS Christophe Rossel, who focused on the EPS activities including the EPS Historic sites project.



The reader may have noticed that the event took place one day before the actual centenary of Ernst Mach death. The choice allowed to many of us to participate in both this event and the commemorative programme on the 19th February, which took place in the town hall of the Moravian capital Brno and in Chrlice. Chrlice, where Ernst Mach was born, makes today a suburban part of Brno. However, as was well noted in Prague, 18th February is coincidentally the day of birth of Ernst Mach. In conclusion, those who do not give a special importance to round numbers could consider the Prague event as a celebration of the 178th anniversary of birth of Ernst Mach. This and the mild winter sun in the Old Town of Prague contributed to the amiable spirit of the event. ■

■ **Jan Mlynář**
President of the Czech Physical Society

▲ **Guests from Austria, from left to right: Peter Schuster, Friedrich Stadler, Ambassador Alexander Grubmayr, Eberhard Widmann**

◀ **The Ernst Mach sculpture. The commemorative plaque is shown in the previous page.**

▼ **The plaque unveiled! From left to right: the city vice-mayor Eva Kislingerova, vice-rector of Charles University Jan Hala, president of the Czech Academy of Sciences Jiri Drahos and president of EPS Christophe Rossel.**

Inspired by light:
close of the International Year of Light

The International Year of Light and Light-based Technologies 2015 (IYL 2015) celebrated its closing ceremony on 4-6 February 2016 in the city of Mérida, Mexico. During three days, over 300 participants reviewed the activities and major outcomes of the IYL 2015 as well as discussed potential legacies of the Year.

One of the main goals of IYL 2015 is to raise awareness worldwide about the many ways photonics could offer solutions for problems of global importance. This was one of the focuses of the message from the Secretary General of United Nations Ban Ki Moon that opened the Closing Ceremony: "IYL 2015 has shown how the science of light, photonics and related technologies can promote sustainable development in many fields, including climate change and energy, agriculture, health and education." In addition, Flavia Schelegel - UNESCO's Assistant Director-General for Natural Sciences - in her message to the ceremony highlighted the importance of practical, cost-effective light-based solutions are becoming increasingly central to the realization of the 2030 Agenda for Sustainable Development.

The academic programme was opened by Ana María Cetto, Chair of the IYL 2015 Committee in Mexico, who welcomed all the attendees and highlighted the importance of the actions done during 2015 that will have a big impact on the future. John Dudley, Chair of the IYL 2015 Steering Committee, gave an overview of the activities developed during the Year. Most notably he highlighted the international coverage of the year with the organization of over 5,000 activities, including scientific conferences, art projects and exhibitions, active learning workshops, festivals and many more, in 148 countries, reaching tens of millions of people. The international impact was also shown by the over 150 partners involved on the organization of the IYL 2015 and more than 15,000 media mentions in 120 countries.

The programme of the conference included lectures and panel discussions by eminent specialists, comprising two recipients of the Nobel Prize in Physics: Shuji Nakamura and John Mather. The different sessions during the closing ceremony addressed the many ways in which light touches us, and of its centrality in our lives. Topics included health and life science, architecture and urban environments, new light sources for research, optics and phototonics, history of optics, cultural heritage, light pollution awareness and science education.

Among the potential legacies discussed for IYL 2015 were the initiative to request the designation by the United Nations of an International Day on Light and Light-based Technologies, the commitment to keep the successful UNESCO's Active Learning in Optics and Photonics (ALOP) programme running in the future, the strengthening of the collaborations between the organizations involved in the organization of the IYL 2015 and the creation of Power For All campaign that involves multi-national NGOs and prominent lighting manufacturers to tackle the problem of light poverty around the world by 2030.

The involvement of the City of Mérida was also of great importance during the Closing Ceremony. Cultural and educational activities for the general public were organized reaching an overall audience of 14,000 people.

During the whole week, scientists visited universities, schools, museums and other public places to give talks around the themes celebrated by IYL 2015 for the general public. The outreach programme also comprised scientific workshops including exciting hands-on activities to bring the science of light closer to the inhabitants of Mérida. Another interesting activity was the IYL 2015 Film Festival, supported by the LIGHT2015 project (1), where a selection of videos/documentaries inspired by IYL 2015 was showcased. The highlight of the Film Festival was the participation of over 1,500 students on the educational programme comprised by short videos focusing on the major themes of the Year followed by an interactive discussion about the topics.

▾ Ana María Cetto during her opening speech.

▾ Art Installation included in the IYL 2015 Closing Ceremony Cultural programme.

All images Credit: Salvador Gutierrez Niño / DGDC UNAM.

▾ Nobel Prize Laureate Shuji Nakamura during his Plenary Lecture.

The ceremony was officially closed with a visit to the archeological site Chichén Itzá, where participants learnt about the ancient Mayan culture and its knowledge of the Universe with two talks from prominent archeoastronomers as well as a light and sound show over the Temple of Kukulcan.

"The IYL 2015 lights that were lit on Paris at the beginning of 2015 are going to be switched off in Chichén Itzá but this does not imply an ending. As the Mayas with their calendar, it is just the ending of one cycle and the beginning of another," stated by Ana María Cetto on her closing speech.

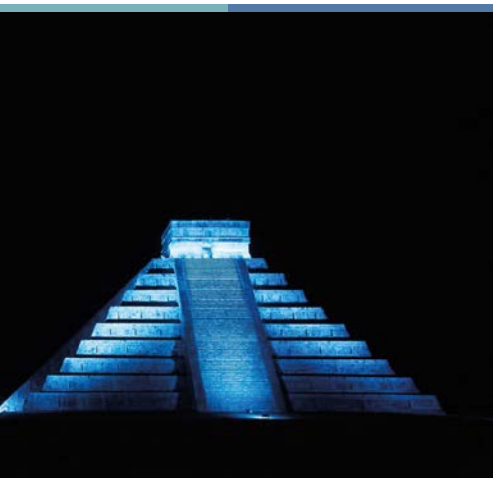
Even though the IYL 2015 is officially closed, its spirit is very much alive. There are many events still happening around the world, for instance France is organizing activities until the end of June to match the school calendar, it is essential to take advantage of the momentum generated and keep walking through the path illuminated by the International Year of Light to ensure a better tomorrow for all. ■

■ Jorge Rivero González & John Dudley

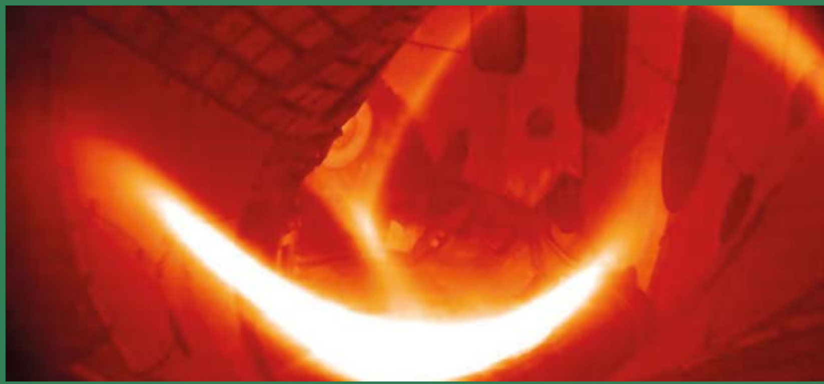
NOTE

[1] The LIGHT2015 project, coordinated by the European Physical Society, is a high-impact outreach and education project to promote the importance of photonics to young people, entrepreneurs and the general public in Europe during the International Year of Light and Light-based Technologies 2015. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 644964. More information: www.europe.light2015.org.

▼ Sound and light show at the archeological site Chichén Itzá.



WENDELSTEIN 7-X FUSION DEVICE PRODUCES ITS FIRST HYDROGEN PLASMA



▲ The first hydrogen plasma in Wendelstein 7-X.

Wendelstein 7-X, the world's largest fusion device of the stellarator type, is to investigate this configuration's suitability for use in a power plant.

Since the start of operation on 10 December 2015 Wendelstein 7-X has produced more than 300 discharges with the rare gas helium. These served primarily to clean the plasma vessel. The cleaner the vessel wall, the higher the plasma temperature, finally reaching six million degrees. In addition, plasma heating and data recording were tested, and the first measuring facilities for investigating the plasma were put into operation, including complex instrumentation such as X-ray spectrometers, interferometers, laser scattering and video diagnostics.

"This makes everything ready for the next step", states Project Head Professor Dr. Thomas Klinger. "We are changing from helium to hydrogen plasmas, our proper subject of investigation."

The first hydrogen plasma, which was created on 3 February 2016 at a ceremony attended by numerous guests from the realms of science and politics, marks the start of scientific operation of Wendelstein 7-X. At the push of a button by Federal Chancellor Angela Merkel, a 2-megawatt pulse of microwave heating transformed a tiny quantity of hydrogen gas into an extremely hot low-density hydrogen plasma. This entails separation of the electrons from the nuclei of the hydrogen atoms.

Confined in the magnetic cage generated by Wendelstein 7-X, the charged particles levitate without making contact with the walls of the plasma chamber. "With a temperature of 80 million degrees and a lifetime of a quarter of a second, the device's first hydrogen plasma has completely lived up to our expectations", states Dr. Hans-Stephan Bosch, whose division is responsible for operation of Wendelstein 7-X. ■

■ © Max Planck Institute for Plasma Physics (IPP)

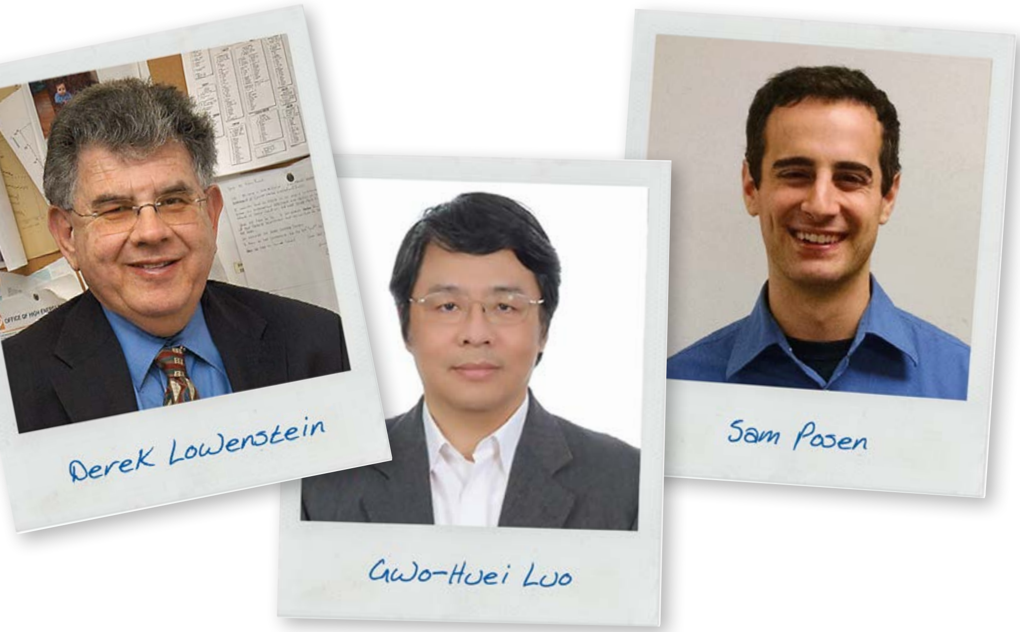
▶ Federal Chancellor Angela Merkel pushed the button. Watching the result on the monitor: Prof. Thomas Klinger/IPP, Prof. Sibylle Günter/IPP, Prof. Otmar Wiestler, Präsident of the Helmholtz Society, Chancellor Angela Merkel, Minister-President Sellering and Dr. Christoph Biedermann/IPP.

2016 Asian Committee for Future Accelerators (ACFA)/IPAC'16 Accelerator Prizes

IPAC'16 is the seventh International Particle Accelerator Conference, a conference that rotates annually between Asia/Oceania, Europe, and the Americas. Since 2010, IPAC has been the premier event in the field of particle accelerators, attracting scientists, engineers, and students from accelerator laboratories and universities around the world.

The ACFA/IPAC Accelerator Prizes are awarded every three years in conjunction with an International Particle Accelerator Conference (IPAC) taking place in Asia. IPAC'16 will take place in Busan, Korea from 8 to 13 May, 2016 (IPAC16.org).

The prizes are named in honour of outstanding scientists. More information on them can be found in: www.ipac16.org/general/accelerator-prizes.html



Under the Chairmanship of Shin-ichi Kurokawa, COSYLAB and KEK, the 2016 prize winners were decided in January this year, as follows:

The Xie Jialin Prize for outstanding work in the accelerator field, with no age limit is awarded to **Derek Lowenstein, BNL,** *"for his many years of leadership in the accelerator field especially that in the AGS Booster and BNL Relativistic Heavy Ion Collider (RHIC). He led the construction of the AGS Booster, which culminated in the world-record proton intensity in the AGS. This work also formed the basis for the establishment of the NASA Space Radiation Laboratory. He was instrumental in realizing this dedicated facility to study radiobiological effects important to human spaceflight to Mars or other planetary missions. He continued his leadership in overseeing the commissioning, operation and upgrades of RHIC, the world's first heavy ion and polarized proton particle collider. RHIC is a highly successful accelerator facility with its unprecedented flexibility and outstanding luminosity performance."*

The Nishikawa Tetsuji Prize for a recent, significant, original contribution to the accelerator field, with no age limit is awarded to **Gwo-Huei Luo, NSRRC, Taiwan,** *"for his outstanding contributions to accelerators at NSRRC, Taiwan, especially for his leading role in the management, construction, and commissioning of the Taiwan Photon Source (TPS). He has successfully brought the TPS project into a real bright light source. His dedication, broad expertise and leadership has contributed in a critical way to the success of the TPS, which must satisfy a number of challenging conditions that do not exist for a green-field machine. The other challenge was using superconducting cavities towards high current and high RF power. The construction of the superconducting RF system was indeed successful, and within four months after the start of operation of superconducting cavities in summer 2015, TPS has achieved a storage of 520 mA beam current that surpasses the design goal."*

The Hogil Kim Prize for a recent, significant, original contribution to the accelerator field, awarded to an individual in the early part of his or her career is awarded to **Sam Posen, Fermilab, USA,** *"for recent important, original contributions to accelerator technology, especially to the development of Nb_3Sn-film-coated superconducting rf cavities. Dr Posen's achievements include in particular developing a process for producing a special Nb_3Sn film on Nb and demonstration of excellent performance in critical field and Q-factor which are expected to outperform traditional Nb cavities. This discovery promises great improvements in the performance of future accelerator."*

The Mark Oliphant Prize for a student registered for a Ph.D. or diploma in accelerator physics or engineering, or to a trainee accelerator physicist or engineer in the educational phase of his or her professional career, for the quality of work and promise for the future will be decided during IPAC'16. The Mark Oliphant Prize candidates are shortlisted from applications supported by references from supervisors, and on the basis of work proposed for presentation at the conference. The candidates are judged during the Student Poster Session at the outset of the conference. ■

Christine Petit-Jean Genaz
EPS-AG

First direct detection of gravitational waves

September 14th 2015, 09:50:45 UTC the whole Earth has been "mildly shaken" by the passage of a gravitational wave and has produced what in my opinion has been the most intense half second of the whole history of physics on this planet.

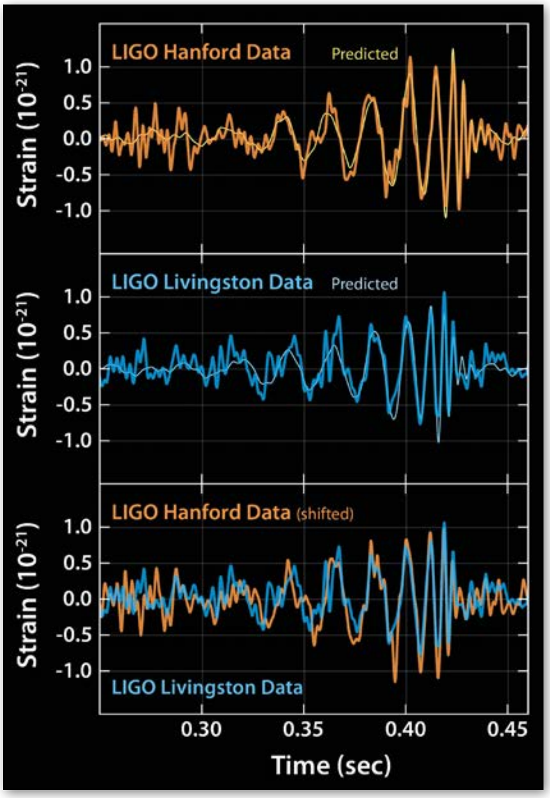
A messenger never seen before has arrived after a journey lasting 1.3 billion years, bringing us the news that a massive black hole was born as the result of a merger of two smaller black holes.

The two detectors of the Laser Interferometer Gravitational-Wave Observatory, Ligo, simultaneously observed a transient gravitational-wave signal. The signal swept upwards in frequency from 35 to 250 Hz, and its noise margin with respect to background noise is good.

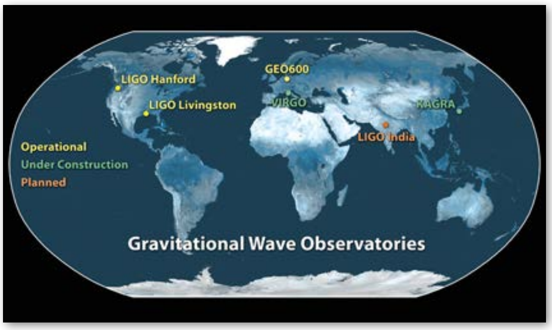
The agreement with General Relativity predictions is very high: models tell us that it was a merger of two massive Black Holes, with mass 36 and 29 $M_\odot$, distant 410 Mpc from us. Such an event has a false alarm rate of less than 1 event per 203,000 years, which is equivalent to say that the significance is greater than 5.1σ. The merger has produced a Black Hole with 62 $M_\odot$, while an energy equivalent to 3 $M_\odot$ was radiated as gravitational waves emission. The two interferometers tell as well that the source was located on an annulus section of 590 deg^2, primarily in the southern hemisphere.

The beauty of this is in front of us; detailed information is quickly becoming available: already 11 papers provide detailed information on the nature of the event, errors are typically of the order of 20%. The fact that gravitational waves interact weakly, on one side has made direct detection very challenging, on the other side the detection, once done, brings very clear information on an event distant in space and time. This is what has motivated the effort of many scientists for so many years.

Not only scientific papers, but a big impact on the world outside fundamental science.



▲ FIG.1: These plots show the signals of gravitational waves detected by the twin LIGO observatories at Livingston, Louisiana, and Hanford, Washington. The signals came from two merging black holes, each about 30 times the mass of our sun, lying 1.3 billion light-years away. The top two plots show data received at Livingston and Hanford, along with the predicted shapes for the waveform. These predicted waveforms show what two merging black holes should look like according to the equations of Albert Einstein's general theory of relativity, along with the instrument's ever-present noise. Time is plotted on the X-axis and strain on the Y-axis. Strain represents the fractional amount by which distances are distorted. As the plots reveal, the LIGO data very closely match Einstein's predictions. The final plot compares data from both detectors. The Hanford data have been inverted for comparison, due to the differences in orientation of the detectors at the two sites. The data were also shifted to correct for the travel time of the gravitational-wave signals between Livingston and Hanford (the signal first reached Livingston, and then, traveling at the speed of light, reached Hanford seven thousandths of a second later). As the plot demonstrates, both detectors witnessed the same event, confirming the detection.



What we have is the first gravitational wave direct detection, the first experimental evidence of a two-bodies merger, the first direct evidence of the existence of black holes. More will come in the future since shortly the two Ligo detectors will be back operational with improved sensitivity and two more instruments, Virgo and Kagra, will be operational, giving the possibility to trace back the event and identify the location of the source. GEO600 is the antenna in Germany, it is a bit less sensitive since it has shorter arms (600m), and it is used for high sensitivity developments as for example the squeezing.

The universe is fascinating and has always new surprises for us, there is always something new to see, but the effort behind the realization of these interferometers has been huge. Behind these results there is the coordinated effort of a community that started to form 30 years ago when the basic ideas were established and is now a large and well organized group. The maximum difference in length between the two arms of the interferometer is now dx=4.10^{-18} m, the background noise of the instrument is 24 times less than that. The amplitude of the wave is measured measuring its strain, and large apparatuses are necessary: the present interferometers have arm length L=4 kilometers, the strain of the wave is dx/L. We are

◂ FIG.2: Current operating facilities in the global network include the twin LIGO detectors—in Hanford, Washington, and Livingston, Louisiana—and GEO600 in Germany. The Virgo detector in Italy and the Kamioka Gravitational Wave Detector (KAGRA) in Japan are undergoing upgrades and are expected to begin operations in 2016 and 2018, respectively. A sixth observatory is being planned in India. Having more gravitational-wave observatories around the globe helps scientists pin down the locations and sources of gravitational waves coming from space.

▲FIG.3: The LIGO Laboratory operates two detector sites, one near Hanford in eastern Washington, and another near Livingston, Louisiana. This photo shows the Livingston detector site.

All figures © Caltech/ MIT/LIGO Lab

talking of a large experimental apparatus in which every single cable must be positioned with adequate care! Interferometry was ready since many years, theory of resonant optical cavities and the topology of the apparatus as well, but it has been necessary to implement it as a well organized ROBOT in order to guarantee a very high duty cycle, as the arrival time of an event is unknown. This progress has been made possible by the evolution of lasers, reference stable sources, developments in mirrors manufacturing, study of the material and the definition of the details of the suspension in order to reduce as much as possible thermal noise. The development of large mirrors with top quality performances has been necessary. As well control theory and the related electronics have also been pushed to their theoretical and technological limits to allow a robust implementation of the interferometer. Gravitational waves detectors are instruments in which top sensitivity and robustness must be combined. Some of these technical achievements have been realized by the industry for other applications, but most of it is the product of the careful and patient study of dedicated people. Let me remind as well the importance to extend the detectability window to lower frequencies: with a detector with a bandwidth above 100Hz it would have been hard to distinguish this event from a normal glitch, and part of the significance of this event would have been missed. In the '80 gravitational waves detectors were focusing at high frequency, above 100Hz. The signals expected from a gravitational wave are extremely small, and a large effort has been dedicated to reduce all noise sources, in order to enlarge the bandwidth of the antenna as much as possible. In particular it has been commonly thought that the detection would have not been possible below 100 Hz, since the seismic noise, which affects all experiments based on Earth, is rather high. The seismic motion at low frequency is nano-metres high for 1 second measurements, and a large piece of experimental work has been dedicated to the seismic isolation and the control of the mirrors, which must keep the whole interferometer on the so called dark fringe, which is the position in which the noise is minimum.

Not only that: to keep people motivated for such a long time has been another big issue, all the analysis pipelines were ready when the event has arrived.

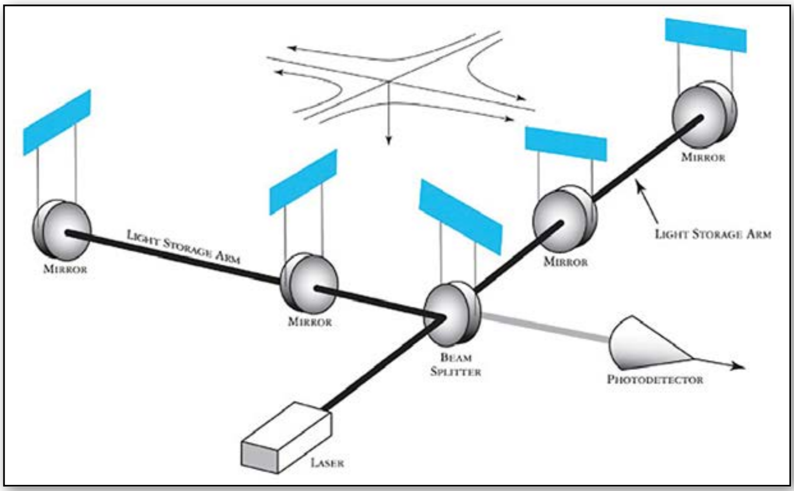
Finally the decision to come out with the discovery 5 months after the event, which I must say was clear since the beginning, has been as well a good decision: it has given to this community the opportunity to support and describe this fraction of a second with the authoritativeness it deserves.

This is the birth of gravitational astrophysics, and we should not forget to cite the fathers of the interferometric gravitational antennas: Reiner Weiss, and Kip Thorne in US, Adalberto Giazotto and Alain Brillet in Europe. ■

■ **Angela Di Virgilio**
INFN-Sezione di Pisa, Pisa Italy

▲FIG.4: The photo shows one of LIGO's test masses installed as the 4th element in a 4-element suspension system. "Test masses" are what LIGO scientists call the mirrors that reflect the laser beams along the lengths of the detector arms. The 40 kg test mass is suspended below the metal mass above by 4 silica glass fibers.

▼FIG.5: Basic schematic of the gravitational wave interferometers, with an incoming gravitational wave depicted as arriving from directly above the detector. The light from the Laser source is divided in two beams by the Beam-Splitter. The two beams produced travel along the two 4km arms. Inside each arm there are two mirrors forming a resonant Fabry-Perot cavity; they are essential to enhance the gravitational wave signal. The interference of the two beams reflected back from the two cavities is modulated by any change in the length of the two cavities. The interference is detected by the photodiode, and the signal acquired. The mirrors and the beam-splitter are suspended in order to reduce seismic noise.



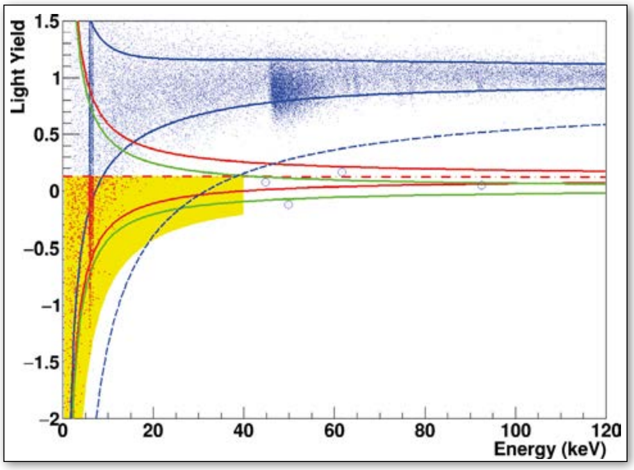
Highlights from European journals

EXPERIMENTAL PHYSICS

Bright sparks shed new light on the dark matter riddle

Highest sensitivity detector ever used for very light dark matter elementary particles

The origin of matter in the universe has puzzled physicists for generations. Today, we know that matter only accounts for 5% of our universe; another 25% is constituted of dark matter. And the remaining 70% is made up of dark energy. Dark matter itself represents an unsolved riddle. Physicists believe that such dark matter is composed of (as yet undefined) elementary particles that stick together thanks to gravitational force. In a study recently published, the authors use the so-called phonon-light



▲ Data gathered by the detector module Lise depicted in the light yield energy plane.

technique to detect dark matter. They are the first to use a detection probe that operates with such a low trigger threshold, which yields suitable sensitivity levels to uncover the as-yet elusive particles responsible for dark matter. The asymmetric dark matter particle models are one of the candidates for a new elementary particle to explain dark matter. The experimental detection is no different from the scattering of two billiard balls, as the particle scatters on an atomic nucleus. The challenge: the lighter the dark matter particle is, the smaller the energy deposited in the crystal used for detection is. Currently, no other direct dark matter search method has a threshold for nuclear recoils as low as 0.3 keV. As such, the CRESST-II team are the first to ever probe dark matter particle masses at such low mass scale. ■

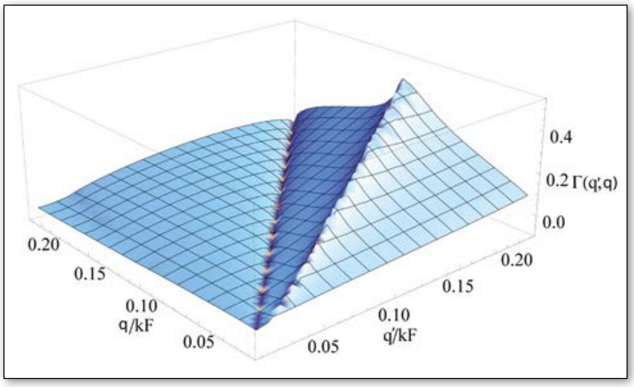
G. Angloher +39 co-authors,
'Results on light dark matter particles with a low-threshold CRESST-II Detector', *Eur. Phys. J. C* **76**, 25 (2016)

CONDENSED MATTER

Helping turn waste heat into electricity

How the collective motion of electrons interacting with bismuth crystal atoms can be fine-tuned to harvest excess heat

At the atomic level, bismuth displays a number of quirky physical phenomena. A new study reveals a novel mechanism for controlling the energy transfer between electrons and the bismuth crystal lattice. Mastering this effect could, ultimately, help convert waste heat back into electricity, for example to improve the overall efficiency of solar cells. These findings have been published now. The author investigates the collective motion of electrons in bismuth, which behaves in a fluid manner with waves propagating in it, a phenomenon referred to as a low energy plasmon. This study demonstrates that the low energy plasmons, when tuned to the same wavelength as the lattice vibrations of the bismuth crystal, or phonons, can very efficiently slow lattice motion. In essence, this plasmon-phonon coupling mechanism, once intensified under specific conditions, could be a new way of transferring energy between electrons and the underlying crystal lattice.



▲ The resonant structure of electron scattering on the bismuth lattice.

One implication is that the plasmon-phonon coupling can help to explain a long-since observed, significant effect in bismuth: the so-called Nernst effect. This occurs when a sample is warmed on one side and subjected to a magnetic field, causing it to produce a significant electrical voltage in the perpendicular direction. Hence it turns heat into useful electricity. ■

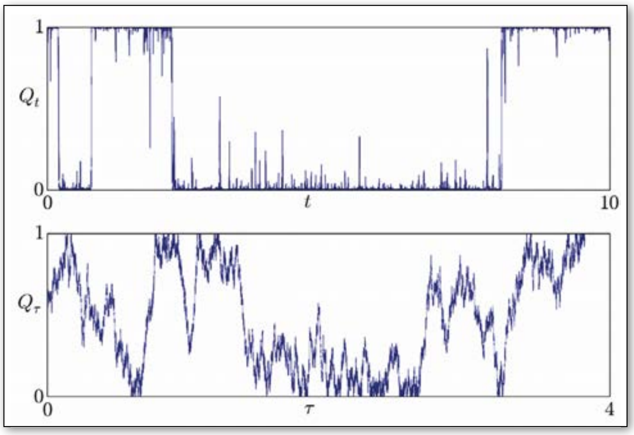
P. Chudzinski,
'Resonant plasmon-phonon coupling and its role in magneto-thermoelectricity in bismuth', *Eur. Phys. J. B* **88**, 344 (2015)

QUANTUM PHYSICS

Unfolding **quantum jumps**

A novel way of defining time parameterisation in continuous measurements sheds a new light on quantum jumps and helps unravel hidden phenomena.

The evolution of a continuously and weakly monitored quantum system is given by a quantum trajectory. The stronger the measurement gets, the less regular the trajectory becomes with the progressive emergence of seemingly instantaneous jumps and sharp spikes which make the analysis of this interesting regime difficult in practice. The authors have proposed to locally redefine time as a function of the measurement back-action in order to blow up the details which are lost in physical time. This new parameterisation unfolds quantum jumps which become continuous and provides a well defined strong measurement limit. This method yields a finer description than the standard von Neumann projective approach to strong measurements: anomalous observables that show non-zero fluctuations in the former would appear trivial in the latter. In addition to its theoretical interest, the technique presented has the advantage of being readily applicable to existing experimental datasets. ■



▲ Example of a quantum trajectory displayed in real time (top) and in effective time (bottom).

▮ **M. Bauer**, **D. Bernard** and **A. Tilloy**,
'Zooming in on quantum trajectories', *J. Phys. A: Math. Theor.* 49, 10LT01 (2016)

ATOMIC AND MOLECULAR PHYSICS

Anti-hydrogen origin revealed by collision simulation

Numerical model takes us one step closer to understanding anti-hydrogen formation, to explain the prevalence of matter and antimatter in the universe.

Anti-hydrogen is a particular kind of atom, made up of the antiparticle of an electron—a positron and the antiparticle of a proton—an antiproton. Scientists hope that studying the formation of anti-hydrogen will ultimately help explain why there is more matter than antimatter in the universe. In a new study published recently, the authors demonstrate that the two different numerical calculation approaches they developed specifically to study collisions are in accordance. As such, their numerical approach could therefore be used to explain antihydrogen formation. The authors employed two very different calculations —using a method dubbed coherent close-coupling — for both one- and two-centre collisions respectively in positron scattering on hydrogen and helium. Interestingly, they obtained independently convergent results for both approaches. Such convergence matters, as it is a way to ascertain the accuracy of their calculations for anti-hydrogen formation.■

▲ Scientists studying the formation of antihydrogen ultimately hope to explain why there is more matter than antimatter in the universe. © vpardi / FotoliaBernd Müller

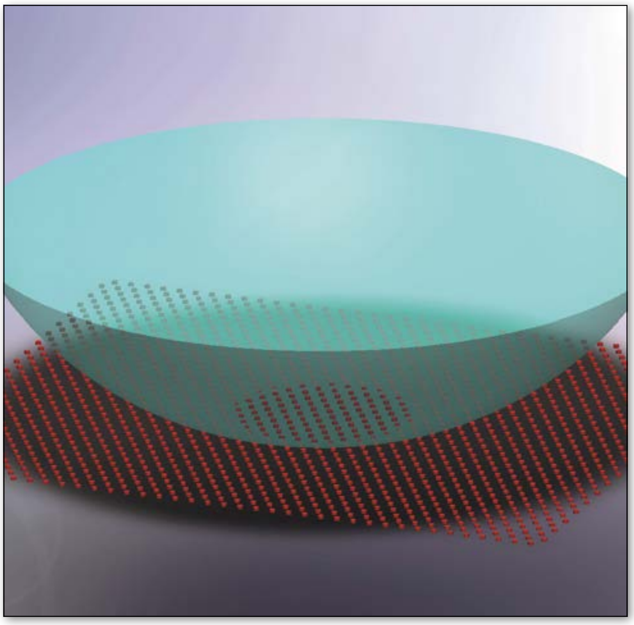
▮ **I. Bray**, **J. J. Bailey**, **D. V. Fursa**, **A. S. Kadyrov** and **R. Utamuratov**,
'Internal consistency in the close-coupling approach to positron collisions with atoms', *Eur. Phys. J. D* **70**, 6 (2016)

CONDENSED MATTER

Adjustable adhesion power: what fakirs can learn from geckos

The authors have now developed a model to study the importance of adhesion in establishing contact between two patterned, yet elastic, surfaces. Nature is full of examples of amazing adjustable adhesion power, like the feet of geckos, covered in multiple hairs of decreasing size. Until now, most experimental and theoretical studies have only focused on the elastic deformation of surfaces, neglecting the adhesion forces between such surfaces. This new approach just published, matters when the scale of adhesive forces, is comparable to elastic forces on materials such as tyres. What the authors focused on was the transition between what they describe as the "happy fakir" scenario, where the sphere hardly presses against the pillars, and the "impaled fakir" scenario, where there is a strong adhesion between the two surfaces. By comparing experimental data on the size of the contact area--which gives rise to the so-called van der Waals cohesive forces between the molecules--with the findings of their new theoretical model, they revealed the importance of adhesion between the two different surfaces in establishing contact. ■

▼ **The model of adhesion between two patterned, yet elastic, surfaces.**



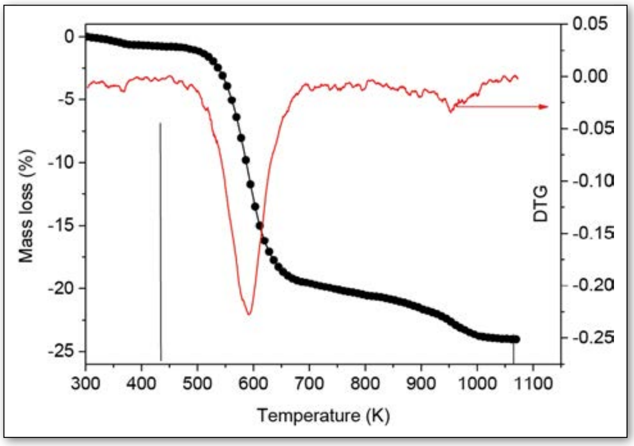
■ **L. Dies**, **F. Restagno**, **R. Weil**, **L. Léger** and **C. Poulard**, 'Role of adhesion between asperities in the formation of elastic solid/solid contacts', *Eur. Phys. J. E* **38**, 130 (2015)

MATERIAL SCIENCE

Scrutinising the tip of molecular probes

Nature of interaction of probe molecules on the surface of oxide particles elucidated

Studies of molecules confined to nano- or micropores are of considerable interest to physicists. That's because they can manipulate or stabilise molecules in unstable states or obtain new materials with special properties. In a new study published recently the authors have discovered the properties of the surface layer in probe molecules on the surface of oxide particles. These properties depend on the interaction at the interface. In this particular study, probes are formed by adsorption of rod-like cyanophenyl derivates on the surface of oxide particles. The



▲ The solid lines indicate the temperature range used to estimate the amount of molecules loaded onto the probe.

authors found that their surface layers behave like glass-forming liquids.

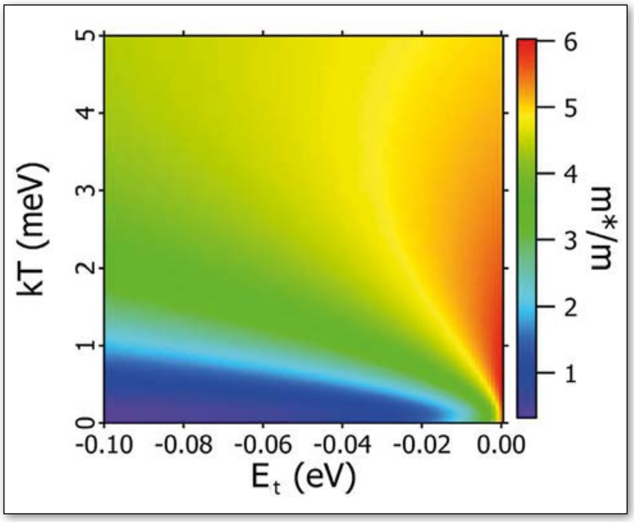
They used data from infrared spectroscopy and thermogravimetry to identify the strength of the interaction between the probe and the oxide surface, which also helped them determine the type of bonding to the surface. The study shows that the value of the surface density can be used to divide the composites into several groups. This helps to determine that the probe molecules applied to the surface of a given group can display similar interactions, as observed in surfaces of the same family. ■

▪ **S. Frunza**, **L. Frunza**, **C. P. Ganea**, **I. Zgura**, **A. R. Brás** and **A. Schönhals**,
'Rod-like cyanophenyl probe molecules nanoconfined to oxide particles: density of adsorbed surface species', *Eur. Phys. J. Plus* **131**, 27 (2016)

CONDENSED MATTER

Lifshitz transitions and correlation effects in ferropnictides

Unconventional superconductivity is observed in heavy fermion systems, cuprates, molecular crystals, and iron-based superconductors close to a point in the phase diagram where as a function of a control parameter (pressure or doping), the antiferromagnetic order is suppressed. A widespread view is that at this point, which is called a quantum critical point (QCP), strong antiferromagnetic fluctuations are a candidate for the glue mediating superconductivity and also account for the normal state non-Fermi-liquid behaviour. Recent ARPES results on ferropnictides have shown that in these compounds the non-Fermi-liquid like scattering rate does not diverge at the QCP, as expected in the quantum critical scenario. Rather, near the QCP it is constant over a large range of the control parameter. In this study, a new scenario is proposed using



▲ Calculation of the effective mass as a function of thermal energy and the shift of the top of a hole pocket (E_t) relative to the Fermi energy.

minimum model calculations: a co-action of hole vanishing Lifshitz transitions and correlation effects is able to explain the ARPES results as well as the strange normal state transport and thermal properties. ■

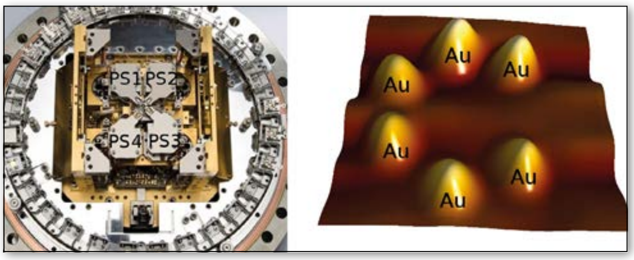
▪ **J. Fink**,
'Influence of Lifshitz transitions and correlation effects on the scattering rates of the charge carriers in iron-based superconductors', *EPL* **113**, 27002 (2016)

APPLIED PHYSICS

Single atom manipulations at the LT-UHV-4-STM

The new ScientaOmicron LT-UHV scanning tunneling microscope is installed at Pico-Lab CEMES-CNRS (Toulouse) with its 4 STM scanners performing on the same surface. At 4.3 K, we report *state-of-art* STM experiments on Au(111) usually performed on the most stable single tip LT-UHV STMs. Operating the 4 scanners independently or in parallel with an inter tip apex distance < 100 nm, the ΔZ stability is better than 2 pm per STM. Single Au atom manipulations were performed

▼ The LT-UHV-4-STM head and a 5.12×5.12 nm^2 STM image of a letter C constructed atom by atom with 6 Au ad-atoms on Au(111) using here scanner PS3. I = 50 pA, V = 500 mV with ΔZ = 0.12 nm. Single atom manipulations tunnel resistance: 333 kΩ.



on Au(111) recording the pulling, sliding or pushing signal. When contacting one Au ad-atom, a jump to contact leads to a perfect linear low voltage I-V characteristics with no averaging. Two tips surface conductance measurements were also performed with one lock-in and in a floating sample mode to capture the Au(111) surface states via two STM tips dI/dV characteristics. This new instrument is exactly 4 times a very precise single tip LT-UHV-STM. ■

J. Yang, **D. Sordes**, **M. Kolmer**, **D. Martrou** and **C. Joachim**,
'Imaging, single atom contact and single atom manipulations at low temperature using the new ScientaOmicron LT-UHV-4 STM', *Eur. Phys. J. Appl. Phys.* **73**, 10702 (2016)

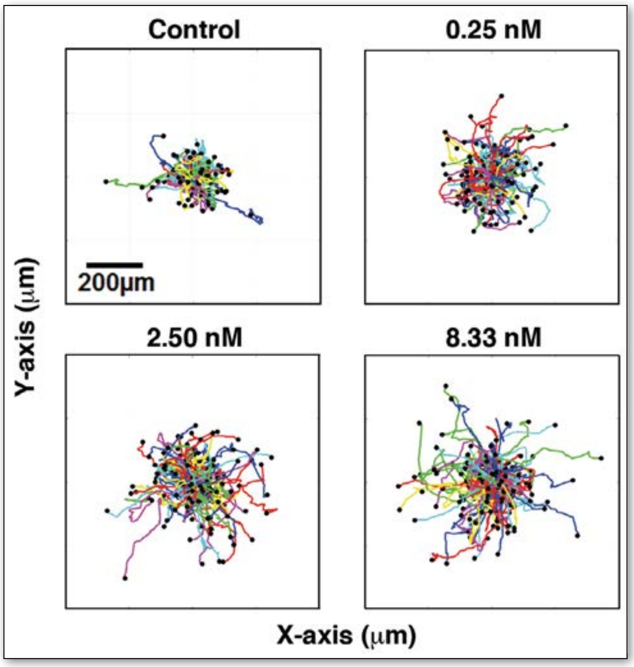
BIOPHYSICS

Physical parameters and **cancer cells' metastatic ability**

Scientists develop potential visual test for diagnosing invasive states of breast cancer cells

The micro-environment surrounding cancer cells is just as important as genes in regulating tumour progression. Scientists have therefore examined the biophysical and biochemical cues occurring in the vicinity of cancer cells. This represents a departure from the traditional measurement of secreted molecules, called biomarkers. The latest research in this field, recently published, found that the presence of a substance called Epidermal Growth Factor (EGF) promotes the motility of elongated mesenchymal tumour cells, which migrate depending on their adhesive properties by climbing along collagen fibres, in contrast to rounded tumour cells, which migrate in an adhesion-independent manner. These findings stem from the work of the authors. The study found that micro-environmental cues linked to the presence of EGF contribute to modulating the mobility of tumour cells—which by their nature can easily change and vary in form. These findings suggests that the cell aspect ratio could constitute a potential visual cue for diagnosing invasive states of breast cancer cells, and ultimately other cancer cells. ■

▾ Plots of single-cell trajectories stimulated by different levels of epidermal growth factor.



D. T. Geum, **B. J. Kim**, **A. E. Chang**, **M. S. Hall**, and **M. Wu**,
'Epidermal growth factor promotes a mesenchymal over an amoeboid motility of MDA-MB-231 cells embedded within a 3D collagen matrix', *Eur. Phys. J. Plus* **131**, 8 (2016)

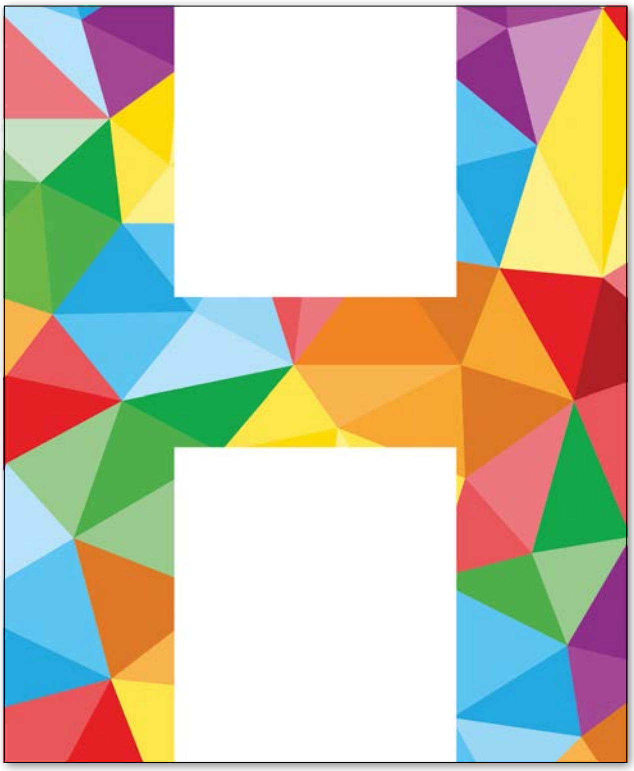
COMPLEX SYSTEMS

Exact formula now available for measuring **scientific success**

Physicists team has developed equations governing the growth of authors' h-index using an agent-based model.

Scientometrics research is the science of evaluating scientific performance. Physics methods designed to predict growth based on a scale-free network have rarely been applied to this

▾ Scientists develop formula to describe the growth of scientists' h-index. © treenabeena



field. Now, the authors have developed an analytical method using a previously developed agent-based model to predict the h-index, probably the most popular citation-based scientific measurement, using bibliometric data. They are the very first to succeed in developing an exact formula to calculate the number of external citations and self-citations for each paper written by an author. These findings have just been published by the authors. It opens the door to applying this growth analysis to social network users or citations from different scientific fields. ■

■ **B. Żogała-Siudem**, **G. Siudem**, **A. Cena** and **M. Gagolewski**,
'Agent-based model for the h-index – exact solution', *Eur. Phys. J. B* **89**, 21 (2016)

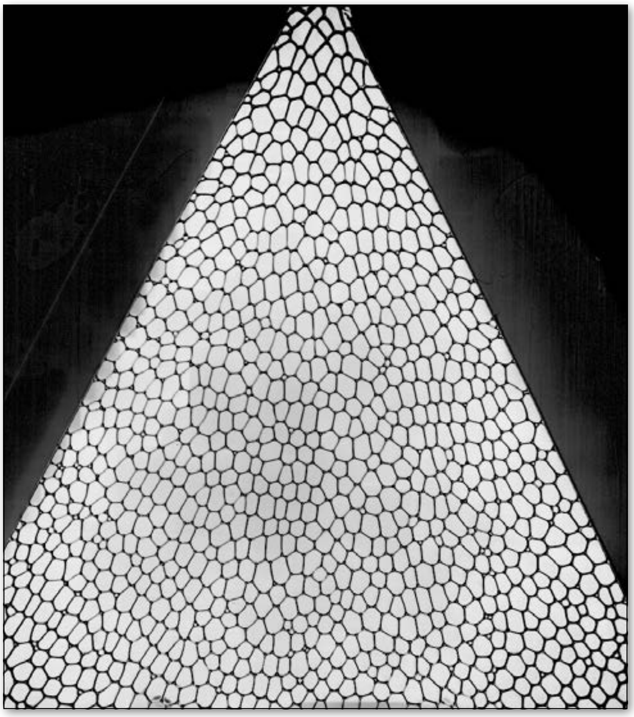
SOFT MATTER

Liquid foam: plastic, elastic and fluid

New study elucidates the plastic flows behind the motion of liquid foams, whose ability to absorb all kinds of waves makes them well-suited as acoustic insulators, or as explosion wave absorbers.

What differentiates complex fluids from mere fluids? What makes them unique is that they are neither solid nor liquid. Among such complex fluids are foams. They are used as a model to understand the mechanisms underlying complex fluids flow. Now, the authors have gained new insights into predicting how complex fluids react under stretching conditions due to the interplay between elasticity, plasticity and flow. These findings were recently published by the authors. Ultimately, potential applications include the design of new, optimised acoustic insulators based on liquid forms, or the mitigation of blast waves caused by explosions.■

▾ Snapshot of a foam in a convergent channel.

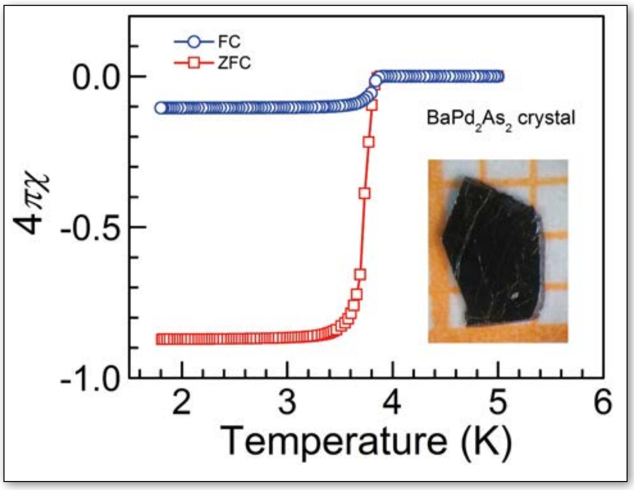


■ **B. Dollet** and **C. Bocher**,
'Flow of foam through a convergent channel', *Eur. Phys. J. E* **38**, 123 (2015)

CONDENSED MATTER

Superconductivity found in $BaPd_2As_2$ single crystal

In this work the single crystal of $ThCr_2Si_2$-type $BaPd_2As_2$ was successfully prepared by a self-flux growth method. The crystal structure was characterized by powder X-ray diffraction method, with the space group *I4/mmm* and lattice parameters a = 4.489(2) Å, c = 10.322(3) Å. From the characterizations of low temperature electrical resistivity, magnetic susceptibility and specific heat measurements, bulk superconductivity was clearly revealed in this compound, although it was not found in other structural types of $BaPd_2As_2$. The superconducting onset T_c (critical temperature) is 3.85 K and the zero resistivity happens at 3.80 K. Surprisingly, this T_c is much higher than those of all other isostructural Pd-based superconductors, such as $CaPd_2As_2$ (T_c = 1.27 K) and $SrPd_2As_2$ (T_c = 0.92 K). The reason that leads to a higher T_c in this compound deserves more detailed studies to understand the underlying mechanism. ■



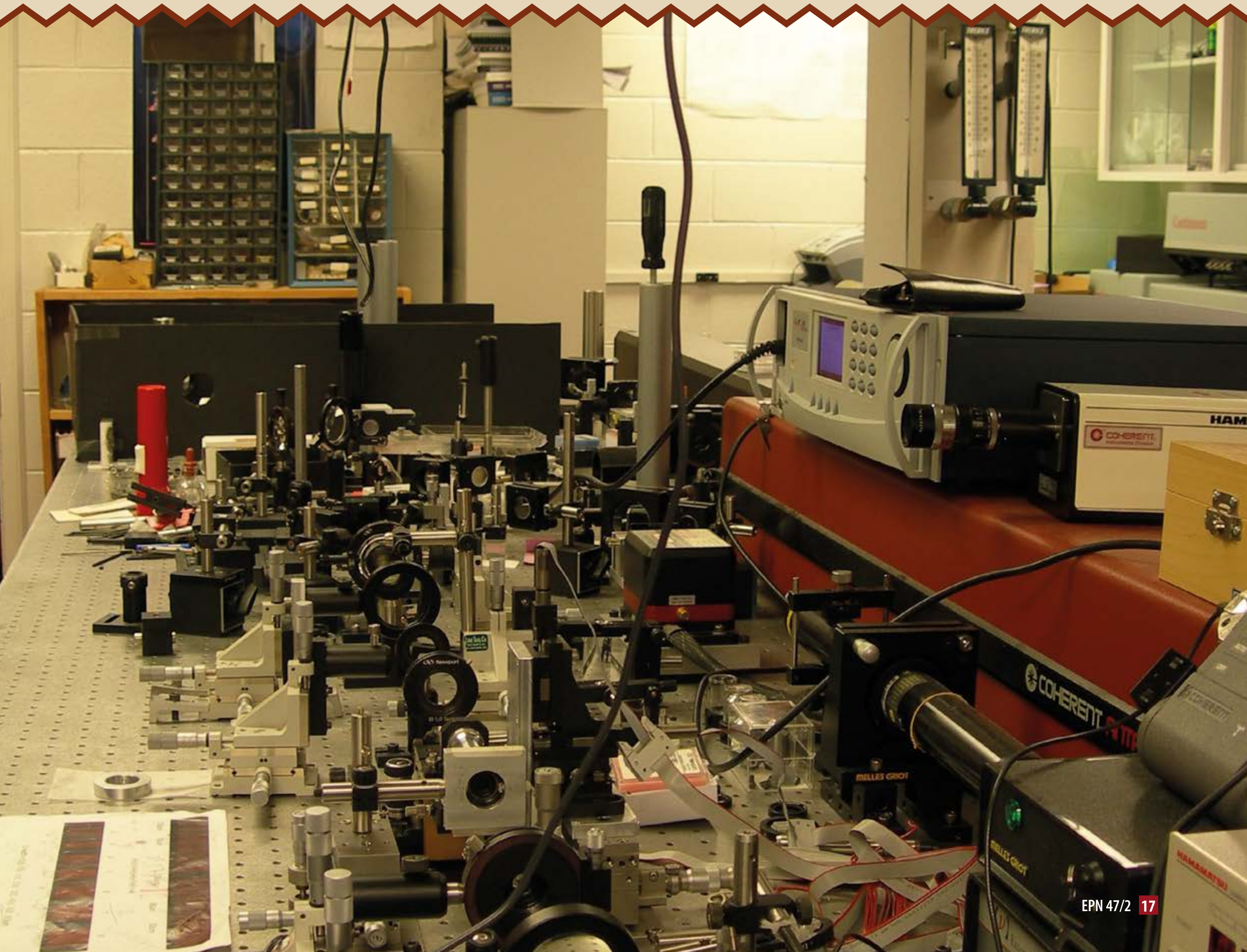
▴ Superconducting Meissner effect in $ThCr_2Si_2$-type $BaPd_2As_2$ crystal.

■ **Q. Guo**, **J. Yu1**, **B.-B. Ruan**, **D.-Y. Chen**, **X.-C. Wang**, **Q.-G. Mu**, **B.-J. Pan**, **G.-F. Chen** and **Z.-A. Ren**,
Superconductivity at 3.85 K in $BaPd_2As_2$ with the $ThCr_2Si_2$-type structure, *EPL* **113**, 17002 (2016)

PT SYMMETRY IN QUANTUM PHYSICS: FROM A MATHEMATICAL CURIOSITY TO OPTICAL EXPERIMENTS

Carl M. Bender – Washington University in St. Louis, St. Louis, MO 63130, USA – DOI: http://dx.doi.org/10.1051/epn/2016201

***Space-time reflection symmetry*, or *PT symmetry*, first proposed in quantum mechanics by Bender and Boettcher in 1998 [1], has become an active research area in fundamental physics. More than two thousand papers have been published on the subject and papers have appeared in two dozen categories of the *arXiv*. Over two dozen international conferences and symposia specifically devoted to PT symmetry have been held and many PhD theses have been written.**



◂ P. 17: The first table-top optics experiment on *PT* symmetry. This experiment is described in Ref. [5]. (Photo taken by Carl Bender during a visit to the laboratory.)

PT-symmetric quantum mechanics is an extension of conventional quantum mechanics into the complex domain. (***PT*** symmetry is not in conflict with conventional quantum theory but is merely a complex generalization of it.) ***PT***-symmetric quantum mechanics was originally considered to be an interesting mathematical discovery but with little or no hope of practical application, but beginning in 2007 it became a hot area of experimental physics. It has now been explored experimentally in such diverse fields as optical wave guides, lasers, optical resonators, microwave cavities, superconducting wires, NMR, graphene, and metamaterials, and this work has been published in such high-impact journals as *Nature*, *Science*, and *Physical Review Letters*. Using techniques developed in these studies it appears likely that it will be possible to use ***PT*** symmetry to develop new ways to control light, perhaps even leading to new kinds of computers that use optical beams instead of electric wires. It may well be used to formulate new kinds of materials and to develop new kinds of communication devices.

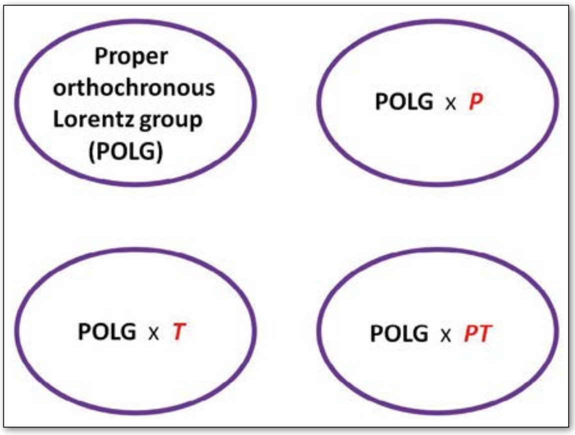
Two profound discoveries

To understand the background of ***PT***-symmetric quantum mechanics, recall that two profound discoveries in the early 20th century transformed classical physics into what we regard today as modern physics. The first was *quantum mechanics*, which describes the nature of matter, the stability of atomic energy levels, the binding of atoms to form molecules, and the properties of materials. The second was *relativity*, which describes the geometry of space and time. Symmetries are a central component of physical laws, and these theories both possess fundamental symmetries, a discrete symmetry in quantum mechanics called *Hermiticity* and a continuous symmetry in special relativity, which is expressed in terms of the *Poincaré group*.

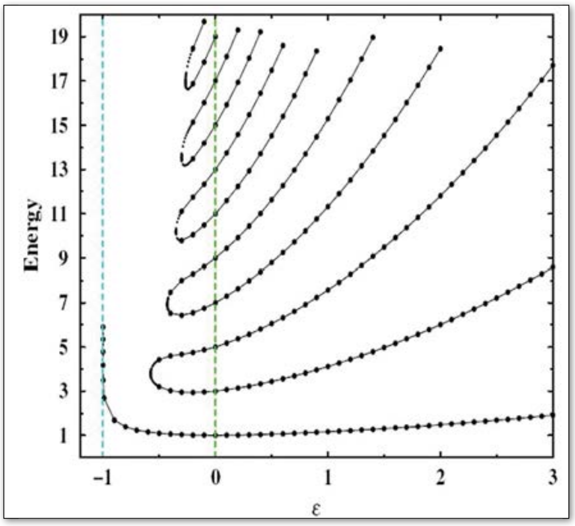
Phenomena such as quantum interference imply that complex numbers play an essential role in explaining physical observations in quantum mechanics. The Schrödinger equation, which is the fundamental equation of quantum mechanics, is complex. It is partly because of complex numbers that quantum theory makes probabilistic rather than definite predictions. (For example, the mass of an unstable particle appears as a pole at a specific point in the complex plane, but on the real axis the remnant of this pole is a probability distribution, and we cannot say exactly what the mass of the particle is.)

Symmetries

While complex numbers are central in quantum mechanics, the symmetries of space-time are restricted to the real domain. A point in space-time is represented by the *real* four-dimensional vector (x,y,z,t). The *Poincaré group*, the continuous symmetry group of space-time, is ten-dimensional: First, there are four *translations*; repeating an experiment in a laboratory located at *different* points in space and time $(x+a,y+b,z+c,t+d)$ will yield the same experimental result. Second, there are three *rotations*; we can rotate about the x, y, and z axes. Repeating an experiment in a laboratory that has been *rotated* in space will yield the same result. Third, we can *boost* the velocity in three possible ways, along the x, y, or z axes. Again, repeating an experiment in a laboratory that is moving at a constant velocity relative to the original laboratory will yield the same result. The homogeneous *Lorentz group* is defined as the six-parameter group of all real 4×4 matrices that perform rotations and boosts (not translations) on the space-time vector (x,y,z,t) but leave the numerical value of the Lorentz scalar $x^2 - t^2$ invariant. For many years it was thought that this six-parameter group (plus translations) was the fundamental geometrical symmetry group of the universe. However, along with the continuous transformations (rotations and boosts), the definition of this group allows for two discrete transformations that we now know are not symmetries of nature. The first, called parity ***P***, changes the sign of the spatial part of the four vector ***P***: $(x,y,z,t) \to (-x,-y,-z,t)$. (This symmetry operation changes one's right hand into one's left hand; such a transformation cannot be achieved by a rotation.) The second, called time reversal ***T***, changes the sign of the time component of the four vector ***T***: $(x,y,z,t) \to (x,y,z,-t)$. A Nobel prize was awarded to Lee and Yang in 1957 for demonstrating that parity is not a symmetry of nature and another was awarded to Cronin and Fitch in 1980 for demonstrating that time reversal is also not a symmetry of nature. (A left-handed laboratory can obtain different experimental results from a right-handed laboratory and a laboratory traveling backward in time can obtain different results from a laboratory traveling forward in time.) After these advances, it was accepted that the correct geometrical symmetry of nature must exclude ***P*** and ***T***.



▸ **FIG. 1:** Structure of the homogeneous Lorentz group, the group of all real 4×4 matrices that leave the Lorentz scalar $x^2 - t^2$ invariant. This group consists of four disconnected parts, a subgroup called the proper orthochronous Lorentz group (POLG), and the elements of the POLG multiplied by parity *P*, time-reversal *T*, and space-time reflection *PT*. If the 4×4 matrices in the Lorentz group are allowed to be complex, we obtain the *complex Lorentz group*, which has only two disconnected parts. In the complex Lorentz group the POLG is joined continuously to the POLG × *PT* and the POLG × *P* is joined continuously to the POLG × *T*.



◂**FIG. 2:** Graph that launched *PT*-symmetric quantum theory. The energy levels of the quantum-mechanical Hamiltonian $H=p^2+x^2(ix)^\varepsilon$ are plotted versus real parameter ε. This Hamiltonian is a complex deformation of the harmonic-oscillator Hamiltonian. It is astonishing that when ε>0, all the energy levels are real even though the Hamiltonian is non-Hermitian. This is because *H* is *PT* symmetric. When ε<0, the energies join in pairs and become complex (not shown). When ε=0, H reduces to the Hamiltonian for the harmonic oscillator, whose energy levels are 1, 3, 5, 7, …

Removing these symmetries from the Lorentz group, we obtain a new smaller symmetry group called the *proper orthochronous Lorentz group* (see Fig. 1).

Extended Lorentz group

What happens if we assume that, as in quantum mechanics, complex numbers play a role in geometry? That is, what happens if we extend the proper orthochronous Lorentz group to include *complex* as well as real 4 × 4 matrices? If we extend the Lorentz group to the complex domain, a new discrete symmetry, namely, ***PT*** *symmetry*, emerges naturally. ***PT*** symmetry means combined ***P*** and ***T*** symmetry; a ***PT*** reflection changes the sign of *all four components* of a space-time vector ***PT***: $(x,y,z,t) \rightarrow (-x,-y,-z,-t)$. For uncharged particles that are their own antiparticles this discrete symmetry is a fundamentally correct symmetry of nature. (For fermions and charged particles, ***PT*** symmetry is augmented with an additional symmetry operator called charge conjugation ***C***, which turns particles into antiparticles. This is the origin of the famous ***CPT*** theorem in particle physics.)

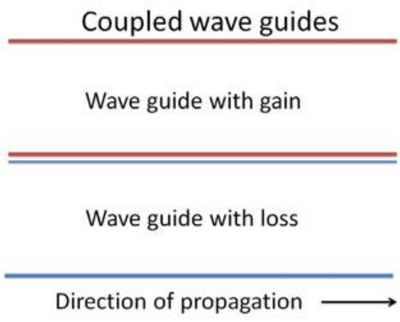
Wigner showed that in quantum mechanics the time-reversal operator ***T*** changes the sign of the imaginary number i. This is because the position operator x and the momentum operator p obey the *Heisenberg algebra:* $xp - px = i$. (This fundamental equation leads to the famous Heisenberg uncertainty principle.) Since the momentum p changes sign (particles reverse direction) under time reversal while the position x does not, i changes sign in order to preserve the Heisenberg algebra. Thus, a ***PT***-invariant combination (one that does not change sign under ***PT***) is ix, and any quantum theory that contains the combination ix is ***PT*** invariant.

The very first ***PT***-symmetric quantum theory, which was proposed in 1998 [1], was defined by the Hamiltonian $H=p^2+x^2(ix)^\varepsilon$ (ε is a real parameter) in which the combination (ix) appears. The notable feature of this Hamiltonian is that it is ***not Hermitian*** and one might think that such a theory should be immediately rejected on this basis. However, it was shown that the theory defined by this Hamiltonian has the two essential properties of a conventional quantum theory: First, the energy levels (eigenvalues of H) are all real and positive if ε is positive. (The energies of this Hamiltonian are plotted in Fig. 2.) The reality of the energy levels for ε>0 was proved rigorously in 2001 by Dorey, Dunning, and Tateo [2]. Second, probability is conserved in time. This condition, called *unitarity*, was established in 2002 by Bender, Brody, and Jones [3].

Upside-down potential

The graph in Fig. 2 is remarkable. It shows that the Hamiltonian $H=p^2+ix^3$, obtained by setting ε=1, actually has real positive energy levels even though it is complex. Moreover, the Hamiltonian $H=p^2-x^4$, obtained by setting ε=2, also has real positive energy levels. This is particularly surprising because $-x^4$ is an upside-down potential! One might think that a classical particle located at $x=0$ and subject to such a potential would slide down to infinity (unless it was precariously balanced at the top of the potential hill). This does indeed happen. However, the particle does not remain at infinity! Complex analysis shows that the particle repeatedly slides right back up to the top of the hill, and actually spends most of its time there. It is extremely unlikely to find the classical particle far from the origin; it is most probable to find the classical particle near $x=0$. At the quantum level a particle in this upside-down potential is in a *bound* state strongly localized at the origin. The explanation for this surprising behavior is that we have extended real space to complex space. Complex numbers differ from real numbers in that the complex numbers are not ordered. If a and b are real numbers, we can say that $a>b$ or $b>a$. However, even though the real numbers are embedded in the complex numbers, we cannot say that one complex number is greater than another complex number, so it makes no sense to say that the "top" of the potential is at $x=0$! One must think in new ways when working in the complex domain.

We learn from this model that quantum theories need not obey the conventional mathematical condition of Hermiticity so long as they obey the physical geometric condition of space-time-reflection symmetry (***PT*** symmetry). ***PT*** symmetry challenges a standard convention in physics—the widely held belief that a quantum Hamiltonian must be Hermitian. And, because ***PT*** symmetry is a weaker condition than Hermiticity, there are infinitely many Hamiltonians that are ***PT*** symmetric but non-Hermitian; we can now study new kinds of quantum theories that would have been rejected in the past as being unphysical. Moreover, ***PT***-symmetric systems exhibit a



▸ **FIG. 3:** ***PT*-symmetric optical wave guide. One wave guide has gain; this is accomplished by shining a laser on an optically active material such as lithium niobate. The other wave guide has loss, which is accomplished by plating the wave guide with a metal such as chromium. The wave guides are coupled by placing them in close physical proximity so that they can exchange energy and achieve equilibrium.**

feature that Hermitian systems cannot; as indicated in Fig. 1, the energy levels become complex when $\varepsilon<0$. The transition from real to complex energies is a key feature of ***PT***-symmetric systems and it is called the ***PT*** *phase transition*. At this transition the system goes from a state of physical equilibrium (called a state of *unbroken* ***PT*** symmetry) to nonequilibrium (*broken* ***PT*** symmetry).

Balanced loss and gain

PT-symmetric systems typically have complex potentials and thus can be thought of as non-isolated systems interacting with their environment. A potential with a positive-imaginary part describes a system that receives energy from its environment; a potential with a negative-imaginary part describes a system that loses energy to its environment. However, a ***PT***-symmetric system is special; the condition of ***PT*** symmetry means that *loss and gain are exactly balanced*. One can fabricate a ***PT***-symmetric system in the laboratory by coupling two identical subsystems, one with gain and the other with loss. (The composite system is ***PT*** symmetric because space reflection ***P*** interchanges the subsystems and time reversal ***T*** switches the roles of gain and loss.) Many experiments, mostly in optics, have readily observed the ***PT*** phase transition between regions of *broken* and *unbroken* ***PT*** symmetry.

The connection between ***PT***-symmetric quantum mechanics and optics was proposed by El-Ganainy *et al.* [4]. The connection is simply that the equation describing the paraxial ray (the wave in the center) of a wave guide satisfies an equation of exactly the same form as the Schrödinger equation except that time t is replaced by z, the distance along the wave guide, and the potential V is replaced by the refractive index n of the optical material. A complex ***PT***-symmetric potential in quantum mechanics (having a balanced gain and loss of energy) is equivalent to a complex index of refraction (having a balanced gain and loss of optical energy). The early optical experiments used a pair of coupled wave guides in which one wave guide had loss and the other had an equivalent gain [5,6] (see Fig. 3). However, there have now been experiments on multiple wave guides [7], ***PT***-symmetric microwave cavities [8], ***PT***-symmetric cavity lasers [9], unidirectional invisibility [10], and optical whispering-gallery resonators [11]. There has also been work on ***PT***-symmetric atomic diffusion [12], superconducting wires [13,14], and ***PT***-symmetric electronic circuits [15].

It is remarkable how quickly the initial theoretical and mathematical work on ***PT***-symmetric quantum mechanics led to a flurry of beautiful experimental work in diverse areas of physics. (Theoretical and mathematical work in many other areas of physics, such as string theory and supersymmetry, has so far failed to give rise to fruitful experimentation even after decades of research.) It is becoming clear that ***PT*** symmetry will have important and lasting practical and commercial applications.

About the Author

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EPL FOR THE IYL 2015

Giorgio Benedek[+] and Graeme Watt[*] – DOI: http://dx.doi.org/10.1051/epn/2016202
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The European Physical Society has greatly contributed to the celebration of the International Year of Light and Light-Based Technologies (IYL 2015) in various ways [1]. In particular Europhysics News has concluded the year 2015 with a Special Issue on the Science of Light which illustrates, through six short reviews, the leading role that Europe in maintaining in several areas of the physics of light and its applications. EPL has played its part by publishing a series of invited IYL Perspectives.

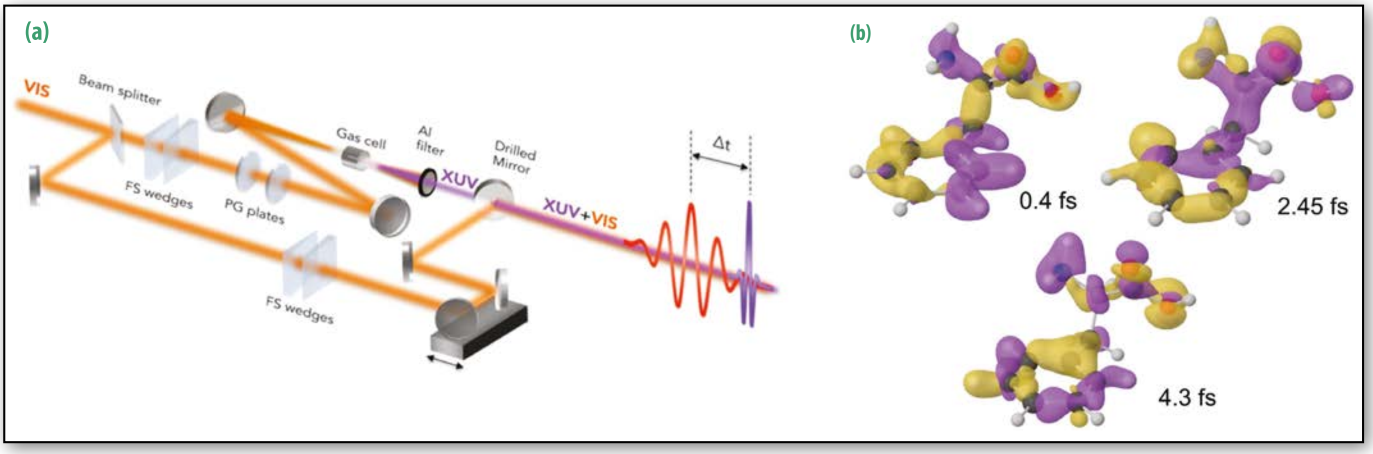
IYL Perspectives

As announced in an EPL Editorial [2] Perspectives are a new type of invited letter-sized reviews on recent advances in some relevant area of physics, presented in a style accessible to a general physics readership. Fourteen IYL Perspectives have appeared so far, covering various important aspects of the physics of light. They have been intercalated by eight Perspectives in other areas of physics, though it is hard to imagine some area of physics that doesn't involve light in some way. The whole set of Perspectives is available in http://iopscience.iop.org/0295-5075/focus/Perspectives. The IYL Perspectives (IYL-PS) appeared in EPL are in many respects complementary to the six EPN reviews: together the set of twenty papers appearing in our two journals form a coherent set covering the most exciting aspects of the physics of light.

The cosmic messenger

Light, as a messenger from the remotest parts of the universe in time and space, tells us about its primordial constitution through the cosmic microwave background (CMB). Jo Dunkley in her IYL-PS [3] summarizes the recent CMB data collected by the Planck satellite and ground-based experiments, and the cosmological properties extracted from that rich information, or expected from upcoming observations. Cosmology relies on general relativity and its validity can now be tested with unprecedented accuracy by means of atomic clocks. The coherent optical link method, where ultra-stable laser light is transferred along optical fibres to synchronize remote clocks, was shown to attain frequency resolutions better than 10^{-18} in 1000 s over 1000 km, thus permitting synchronization over a continental scale (Fig. 1). Calonico *et al.* discuss in *Light and the Distribution of Time* [4] the tremendous progress made in this field and the vast implications in metrology, geodesy, astronomy and cosmology, *e.g.*, in the search for dark matter.

▾**FIG. 1: Light and the distribution of time: Optical Fiber Links in Europe. Solid Lines: existing optical links. Dashed line: ex tensions in progress (from Calonico, Inguscio and Levi [4]).**

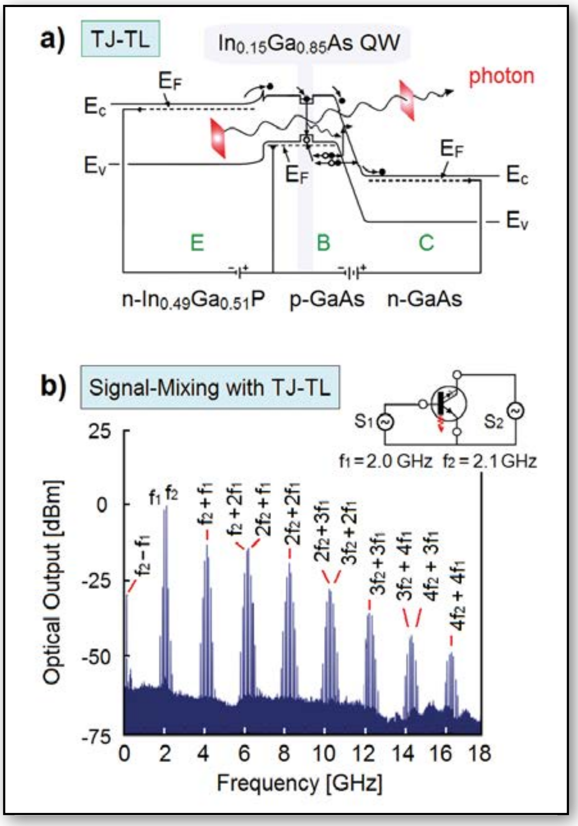


▲ **FIG. 2:** *Light at the extreme:* **(a)** Attosecond experimental setup. The FS wedges: ultrathin fused silica wedges for fine dispersión compensation; PG plates: birefringent plates for polarization gating; Al filter: 100nm thick aluminum filter to block fundamental radiation and to compensate for the intrinsic chirp of attosecond pulses. **(b)** Snapshots of the calculated electron dynamics for three particular pump-probe delays. The figure shows the variation of the hole density with respect to its time-averaged value: yellow and purple correspond to positive and negative values, respectively (from Cerullo, De Silvestri and Nisoli [10])

Extreme light

Attempts to reproduce in ground-based experiments the extreme conditions of matter considered in astro-particle physics are so far the domain of large accelerators. The discovery of laser chirped-pulse amplification (CPA) made in 1985 by Strickland and Mourou [5] and subsequent great advancements [6-8] now allow production of giant laser wakefield accelerations in a solid, and high-energy radiation and particle beams with an extremely short time structure [8] : the CERN on a chip, as Gérard Mourou likes to say! The art of pulse compression down to the atto-second scale has received a strong boost from the Milan Polytechnic group [9,7]: now Cerullo, De Silvestri and Nisoli explain in their IYL-PS [10] how the motion of atoms and electrons can be followed in real time, thanks to these achievement, even across organic molecules (Fig. 2).

The subject of high-intensity laser-atom interactions has been reviewed by Charles Joachain, whose Perspective, starting with a nice historical introduction, has been chosen as a prelude to the IYL series in EPL and was published in the final volume of 2014 [11]. Large-scale European ultra-intense laser facilities like ELI, LMJ and Apollon will soon become operative. The study of condensed matter under extreme conditions planned at PETAL (Petawatt Aquitaine Laser), inaugurated last September at the CEA-CESTA Laser MegaJoule facility near Bordeaux [12], is being illustrated in a forthcoming IYL-PS by Dimitri Batani, anticipated however by an Editor's Choice EPL on shocked-compressed water [13]. There is great expectation from ultra-intense laser facilities for controlled inertial fusion: Stefano Atzeni reviews the state of the art in his IYL-PS [14], reporting on the recent breakthroughs and the potential of alternative schemes, in particular direct-drive shock ignition.



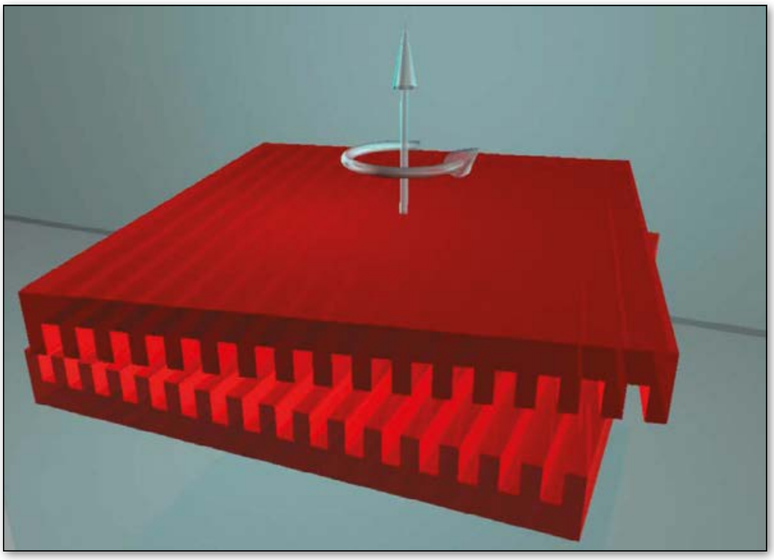
▸ **FIG. 3:** **(a)** Schematic band diagram of a quantum-well tunnel-junction transistor laser (QW TJ-TL) shown with a generic resonator cavity; **(b)** Microwave signal mixing with a common-emitter tunnel junction transistor laser with a pair of input sinusoidal signals: one (f_1=2.0 GHz) at the base using current modulation, and the other (f_2=2.1 GHz) at the collector using voltage modulation. The optical output with harmonics actually extends up to the 11th order, ($4f_1+7f_2$ = 22.7 GHz) despite being limited by amplifier bandwidth (from [15]).

From LED to nano-photonics

A much more familiar use of light is for illumination. A major scientific revolution of the past century was the first realization in 1962 of a visible light-emitting diode (LED) by Nick Holonyak Jr. and S. F. Bevacqua: Nick Holonyak accepted to write with Milton Feng a Perspective for EPL – a great start for the 2015 IYL-PS series! It is well known, however, that Nick Holonyak and Milton Feng made another breakthrough in 2005, the creation of the transistor laser (Fig. 3): this is actually the subject chosen for their Perspective [15]. Most welcome, in view of the great promise that the transistor laser holds in the fields of electro-optics, such as for non-linear signal mixing, frequency multiplication, negative feedback, optoelectronics logic gates and nanophotonics applications! The descent of optics and photonics to the nanoscale was actually celebrated by Zhi-Yuan Li (Beijing Academy of Sciences), who explored in his IYL-PS [16] the concepts, insights, methodologies, and technologies in nanophotonics setting a solid platform to achieve better future technologies that use light as a carrier of energy and information, and as a medium to probe and manipulate the intrinsic properties of matter via light-matter interaction. The IYL-PS by the Madrid group [17] and one by Tongtong Zhu and Rachel Oliver at Cambridge [18] envisage the new avenues that single photon sources implemented in nitride nano-structures will open in quantum photonics and information processing.

Quantum electro-dynamics

Cavity Quantum Electrodynamics (CQED), where a single two-level atom is coupled to a few photons stored in a single mode of a high-quality resonator, besides its fundamental interest in the study of coherent atom-field interactions, provides an ideal situation for the realization of quantum information protocols. In their IYL-PS on trapped quantum light [19], Michel Brune and Jean-Michel Raimond illustrate the fundamental interest of CQED in connection with recent experiments, performed with circular Rydberg atoms and superconducting millimetre-wave cavities. Fundamental aspects of QED can be tested in Casimir force experiments, *e.g.*, by measuring the Casimir torque induced by quantum vacuum fluctuations between two nanostructured plates (Fig. 4), as illustrated in the IYL-PS by Guérout *et al.* [20], or with the experiment proposed by D. S. Ether Jr. *et al.* [21], where optical tweezers are used to probe the Casimir interaction between microspheres inside a liquid medium.

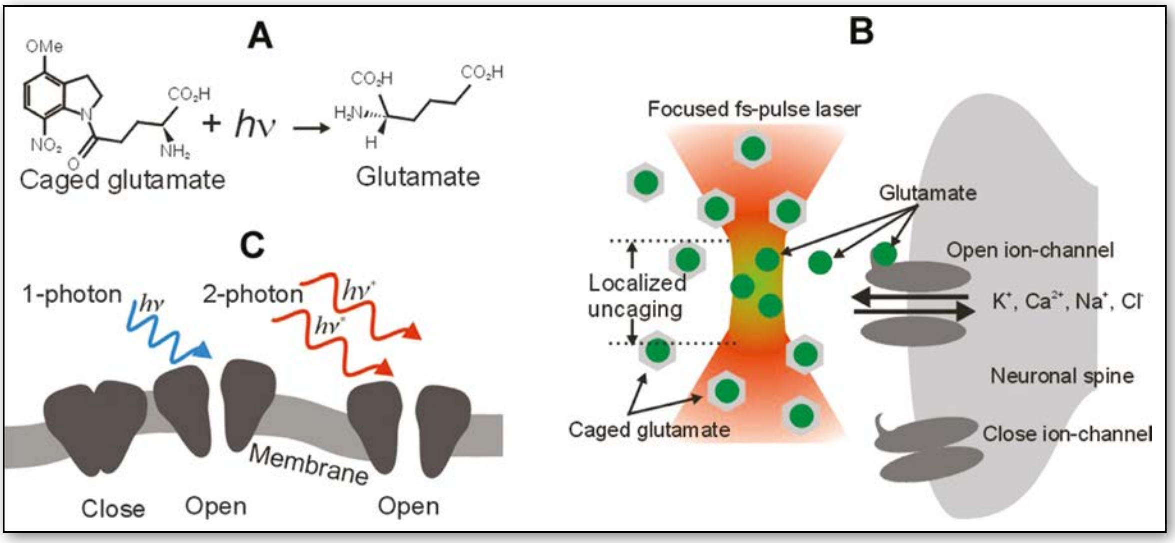


▲ **FIG. 4:** ***Casimir torque between nanostructured plates:*** **Quantum vacuum fluctuations produce Casimir forces when scattered by external boundaries. The figure shows a sketch of the configuration giving rise to a Casimir torque (from Guérout, Genet, Lambrecht and Reynaud [20]).**

Light for graphene and nano-medicine

New domains of optics are worth being emphasized. One is the use of ultrafast THz spectroscopy for the characterization of ultrafast charge carrier dynamics as, *e.g.*, that of Dirac electrons and holes in graphene. The recent experimental work in this rapidly growing and exciting area is reviewed in the IYL-PS by Ivan Ivanov *et al.* at the MPI for Polymer Research in Mainz [22]. The other domain is optics in the vast and rapidly growing field of nano-medicine, a field which would deserve an entire series of IYL Perspectives. Just one fascinating example, due to Vincent Daria and Hans Bachor [23], has been chosen, where optics is shown to be a powerful tool for the analysis of neuronal information processing. In parallel to imaging, laser-based stimulation, *e.g.*, of light-sensitive actuators and reporters in neuronal activity, has become

▼ **FIG. 5:** ***Using light to probe neuronal function:*** **(a) Photochemical reaction for glutamate uncaging. (b) Illustration of 2P uncaging near dendritic spines where neurotransmitter-gated ion channels are located. (c) Light-activated ion channels (*e.g.*, channelrhodopsin) expressed in cell membranes. Ion channels are not drawn to scale (from Daria and Bachor [23]).**

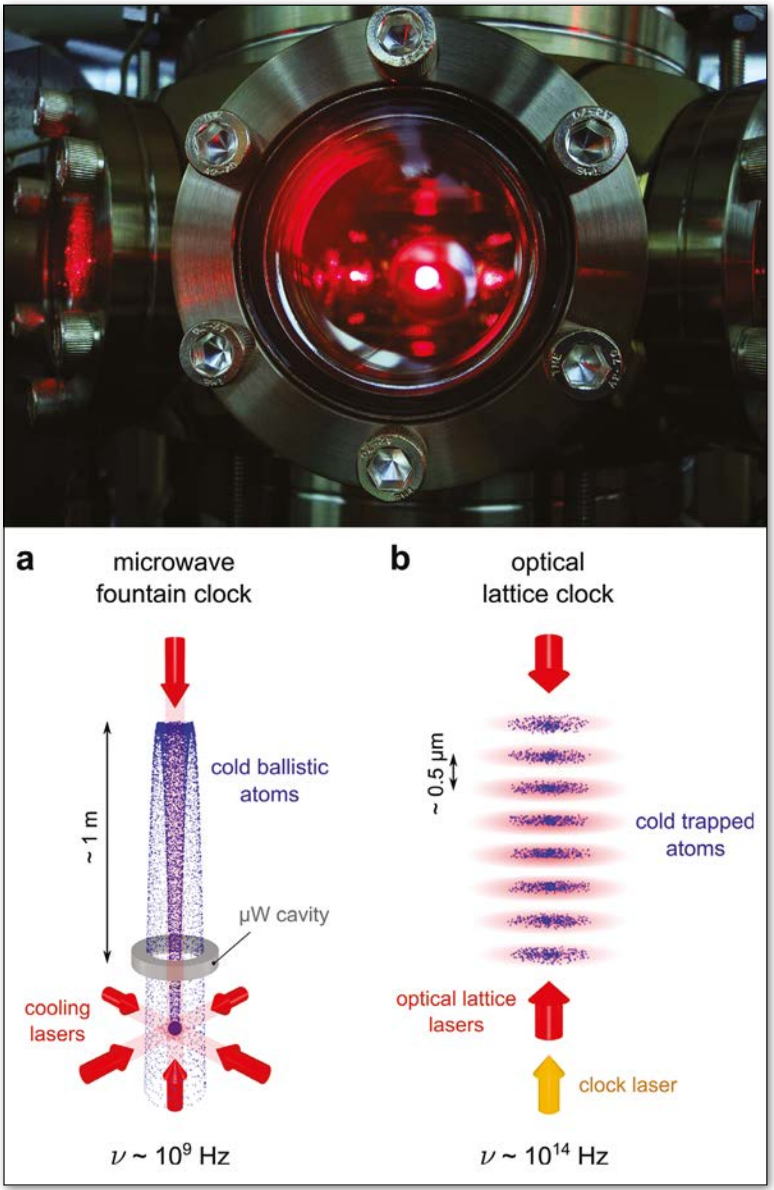


a well-established method to investigate neuronal activity (Fig. 5). Even in *in vivo* experiments the analysis is reaching a resolution to the level of single-neuron response. The authors argue that, besides providing fundamental information on the brain processes and development, optical methods may have medical applications, *e.g.*, in the analysis of mental disorders.

Ultra-cold atoms and the unity of physics

In our descent from the highest energies of astroparticle physics and cosmology, down to the lower and lower energies through ordinary condensed matter, we finally reach the world of ultra-cold atoms. This is another exciting area of modern physics enabled by light via laser cooling and the realization of optical traps and lattices for quantum gases. The thirty-year history of laser cooling up to the recent achievements is summarized in the IYL-PS by Fallani and Kastberg [24]: the demonstration of Bose-Einstein condensation, the simulation and testing of fundamental quantum properties, the realization of laser-cooled clocks for high precision measurements (Fig. 6), the construction of customized synthetic potentials to simulate interactions in other domains of physics, *e.g.*, in QCD, are just examples of the new world of ultra-low temperatures made accessible by light. Much of this field connects with the areas of physics first mentioned in this summary, astroparticle physics, general relativity, cosmology, and fundamental metrology. The circle closes, to remind the essential unity of physics: a unity which goes well beyond the instrumental aspects, to acquire a high conceptual value. For example, the concept of perfect fluid can apply to a strongly interacting ultra-cold Fermi gas as well as to the quark-gluon plasma, or in cosmology to describe Friedmann–Lemaître–Robertson–Walker universe evolution.

▾FIG. 6: *Cold atoms: A field enabled by light:* **(a)** A laser cooling experiment. Inside the vacuum chamber a ball of ~10^9 cold 6Li atoms (the white spot in the centre), at a temperature of ~1 mK, glows while scatters photons from the beams of a magneto-optical trap (courtesy of G. Roati, LENS). **(a,b)** Laser-cooled atomic clocks: (a) In state-of-the-art microwave clocks an atomic fountain provides long interrogation times on the order of one second (a). In the new generation of optical clocks the atoms are trapped in an optical lattice, which freezes the atomic motion and provides Doppler- and recoil-free measurements (b) (from Fallani and Katsberg [24]).



Perspectives for a stronger EPL

Perspectives have met a great success in terms of downloaded content: they systematically appear among the top-10 most-read EPL letters. There seems to be a need for short reviews intended for an audience of physicists working in adjacent fields who want something more technical and richer in references than the usual physics magazine article, but shorter and easier to read than a standard review article written for specialists. Perspectives constitute a further well-received service that the physical societies owning EPL, offer to the worldwide community of physicists. Thus the Perspective series will continue, possibly with a substantial extension in number. However, invited Perspectives are only a small fraction of EPL letters. Most published EPL letters are selected (a bit more than 1/3) out of the submitted manuscripts by an Editorial Board of about 70 outstanding colleagues who represent all branches of physics and all continents, and are entirely and uniquely responsible of the peer-review process.

The number of excellent physics letters produced world-wide largely exceeds what high-impact letter journals, either general or specialized, can host. Not necessarily the best papers are published in the highest IF journals, since the scientific prestige of the paper mostly depends on the scientific prestige of the editors more than on the visibility of the journal. If you feel that your recent work either changes a paradigm; or opens a novel significant research area in physics; or presents a substantial progress in a relevant field of physics; or makes a valuable contribution in a field of broad general interest, closely related to physics, do not hesitate and submit to EPL! ■

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Giorgio Benedek, former Professor of Structure of Matter at the University of Milano-Bicocca and Visiting Professor at the Donostia International Physics Center in San Sebastian, is presently the EPL Editor-in-Chief and Fellow of EPS. He is a condensed matter physicist mainly interested in surface dynamics, surface phonon spectroscopy, electron-phonon interaction, and low-dimensional systems such as nanostructured carbon and quantum droplets.

Graeme Watt has been the Executive Editor for EPL since 2007. In addition to overseeing the smooth efficient publication of the journal he is also responsible for strategy and development. He can be located promoting EPL at many conferences.

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[Letter to the Editor]

by Adelbert Goede

Fellow of the European Physical Society

DOI: http://dx.doi.org/10.1051/epn/2016203

The need for Basic Energy Research

The Paris Conference of the United Nations Framework Convention on Climate Change (UNFCC) may have brought relief to some, the fact remains that climate models, the basis of the politically negotiated limit on earth surface temperature rise, are far from perfect. The ocean exerts large inertia on the coupled atmosphere-ocean system and its interaction is less well understood. For example, Atlantic multi-decadal temperature oscillation, the global-warming hiatus, was not captured by these models. Meridional overturning time scales of the ocean are expressed in centennials rather than decades, which stretches the predictive power of models. Models are starved of deep sea data which carry the heat; below 700m depth hardly any measurement exist to validate the models. This calls for better models and more measurements, lest public opinion turns against current climate policy measures for lack of credibility of the climate forecast.

This is hardly EPS expertise and not the point anyway. At this point in time, given the uncertainties, it is good policy to work on solutions, rather than argue about (imperfect) climate model predictions. The energy transition is EPS core business and this is what we should be concentrating on.

The energy transition is increasingly hampered by its focus on the energy source rather than the system as a whole. For example, large scale deployment of wind farms is based on the upscaling of existing wind turbine technology, rather than basic research needed to solve the intermittency problem at system level including energy storage. Public money is spent on deployment of today's technology. As a consequence, perverse feed-in tariffs, destructive cross border transport and wasteful overcapacity characterise this corner of the renewable energy market.

The EU has set ambitious energy and climate targets. The Strategic Energy Technology (SET) Plan shows what research is needed. Sadly, when it comes to implementation, the EU Horizon 2020 Energy Work Programme 2016-2017 offers precious little opportunity in basic energy research. Most calls are directed at high Technological Readiness Level, aimed at implementation of today's technology. The 2030-2050 energy transition, however, requires investment in basic research and innovation, enabling tomorrow's technology. The EPS should stand up against current EU implementation practise and advocate the need for basic energy research both in Brussels and with their Member State masters. ■

by Franco Bagnoli,
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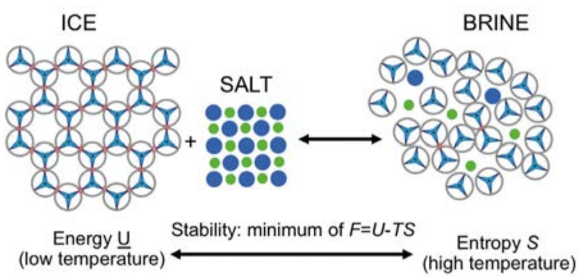
Delicious ice cream
why does salt thaw ice?

During winter, we use to spread salt to thaw ice on the streets. In a physics show, one can be almost sure that after showing this effect, the answer to what happens to temperature will be "it increases". But no! It goes down, in such amount that one can complement the show by producing hand-made ice creams [1].

This phenomenon is also exploited for self-injuring [2] (unbelievers may be asked to hold a salted ice cube in their hand). Clearly, publicly producing almost-instant ice cream with kitchen equipment (*i.e.*, without liquid nitrogen) is an easy way of getting attendees' attention.

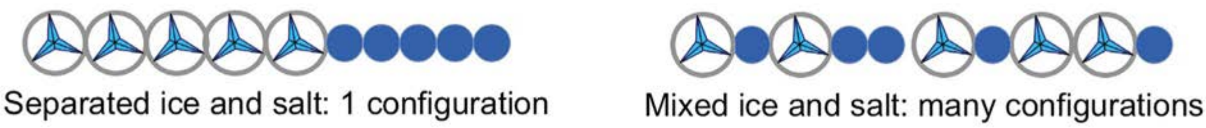
This phenomenon is not so easy to explain because one cannot simply rely on energy considerations. Indeed, water molecules and salt ions (sodium and chlorine) prefer to stay separate from an energy point of view and so they do, below -21 °C.[1]

As can be seen in Figure 1, the chlorine and sodium ions (being charged) fit well among water molecules which are polar, but by doing so they disrupt the ordered structure of ice and salt crystals. As for melting, this implies that the mixture is stable at high temperatures, and that the separate crystals are stable at low temperatures, below -21 °C . So why



▲ **FIG.1:** A schematic representation of the mixture of water and salt ions using the Mercedes-Benz model.

[1] Therefore, it is useless to spread salt on street ice below such temperature.



▲ **FIG.2:** Number of configuration in ordered and disordered arrangements of molecules and ions in a one-dimensional model.

does the temperature go down when salt is mixed with ice?

Let us come back to the previous statement: disordered structures are stable at high temperatures, and ordered ones at low temperatures. The latter is clearly favoured by energy, but the first? We have to introduce the concept of entropy S, which is the (logarithm of) the number of possible configurations.

Using a simple one-dimensional model (Fig. 2), we can appreciate the difference in the number of configurations for ordered and disordered structures. If the difference in energy between the two types of structures is large, the order is preferred with occasional and local fluctuations (for temperatures above the absolute zero and in a classical framework). But if the difference in energy is not so large, fluctuations that raise energy happen more frequently. And when order is destroyed, it is recovered with difficulty because there are so many un-ordered configurations nearby, not so distant in energy, and only one ordered.

Let us invoke the concept of free energy $F = U - T\,S$, where U is the energy and T the temperature. The stability of a system is given by a minimum of F, and from the above formula it is easy to see that the temperature favours the energy when it is low, and the entropy (that has a minus sign) when it is large.

So, when salt is added to ice above -21 degrees, molecules tend to reach a stable configuration by mixing, but this requires energy in order to break the hydrogen bonds of ice and for the dissolution of the salt (the latent heat of ice is 6.01 kJ/mol and the dissolution of sodium chloride requires 3.87 kJ/mol).

And now our challenge (for people using the International System of Units): why is the Fahrenheit scale so weird and why does its zero correspond to (roughly) -18 degrees? [2]

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[2] At the time of Daniel Gabriel Fahrenheit (1686–1736), the mixture of salt, ice and water constituted the lowest temperature easily obtainable without laboratory tools, and was used to define the zero of the Fahrenheit scale (using equal volumes of ice and salt), while 100 degrees corresponded (roughly) to the body temperature [3]. The advantages of this scale is that it never requires negative temperatures in everyday life, and (with the present refined scale) that there is a 180 degree separation between the boiling and freezing points of water, making easier to measure temperatures without decimals.

FASCINATING OPTICS IN A GLASS OF WATER

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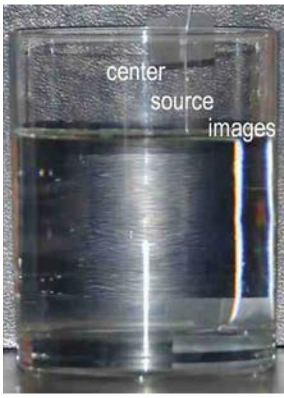
In Ref. [1] Jo Hermans discussed how the image of a horizontal arrow behind a glass of water reverses direction when it is moved away from the glass. The present paper deals with some other interesting effects that can be observed when looking at a drawing (source) taped tightly onto the back of a cylindrical glass of water, or beer, or white wine, whatever the reader prefers.

In order to introduce the topic we take the cartoon from Ref. [1] (Fig. 1a) and tape it onto the back of a glass of water. If we try to take a photo of the cartoon with a camera in autofocus mode it has problems finding the focus. It is possible to focus the camera manually on the horizontal lines in the cartoon, *e.g.*, the upper rim of the beer glass (Fig. 1b) but then the vertical lines are blurred. If the focus is set on the vertical lines (Fig. 1c) all horizontal lines are blurred.

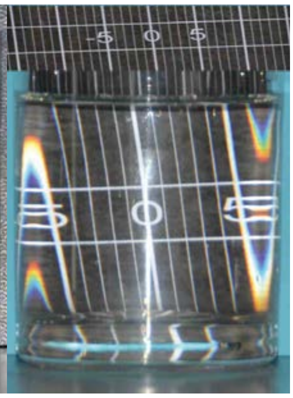
Another interesting effect is observed if a cotton wire is taped vertically onto a glass half-filled with water as in Fig. 2. If the wire is near the center, one image is seen through the water. If the glass is rotated clockwise the wire and its image both move to the right, but the image moves faster than the wire. At some point, surprisingly, a second image jumps in at the right edge of the glass. If the glass is rotated further, the left image moves to the right and the right image moves to the left. At some angle the two images coincide. If the glass is rotated still further both images disappear: the wire is invisible through the water. Also the focal properties of the images, especially in the position where the two images tend to coincide, are surprising, as will be discussed below.

Fig. 3 shows the image of a grid of straight lines, taped onto the glass. It is seen to consist of a series of strongly bent curves with sharp maxima and minima. Near the extrema beautiful rainbow spectra are observed.

All phenomena described in this paper can be understood by using simple geometrical optics. The experiments can be repeated with simple means and observed with the naked eye and/or a camera with manual focus.



▲ **FIG. 2:** Picture of a cotton thread vertically taped onto the back of a glass partially filled with water. The middle of the glass is shown by the line of reflection of the flash light. The cotton thread (source) can be seen through the glass above the water level. The two images can be seen on the right.



▲ **FIG. 3: Top:** Slightly tilted grid of white straight lines on a black background. **Bottom:** Picture of the grid through the water.

▼ **FIG. 1: (a)** Cartoon, obtained from Ref. 1, which is used as source in Figs. b and c. **(b)** Photo taken through a plexiglass cylinder with the camera focus on the upper rim of the glass of beer. **(c)** Photo with the focus on the left vertical edge of the glass of beer.

The position of the image

The perception of depth has several definitions [2],[3]. One is the binocular depth perception where the position of the image is determined by the point of intersection of one light ray reaching the right eye and the other ray reaching the left eye. In the *monocular* depth perception the position of the observation point is varied only over the diameter of the pupil of the eye (a few mm). This is also used by the eye to observe an image as sharp.

The system under consideration is essentially three dimensional, even if the source and the observer are in one horizontal plane. Two light rays in the vertical plane are deflected by a straight line (Fig. 4) while two rays in the *horizontal* plane are deflected by a circle (Fig. 5). As a result the positions of the images, constructed with rays in the vertical plane or in the horizontal plane, differ. This difference is a well-known property of astigmatic lenses ([3], page 162). In fact, it is used as a test for astigmatism.

Rays in the vertical plane

First we calculate the position x_I of the image of a source (object) at x_S in a medium with index of refraction n and a flat surface (perpendicular to the x-axis) to air at x_B. This corresponds with light rays in the vertical plane of our problem. Using Fig. 4 we find

$$h = (x_B - x_S)\tan\varphi = (x_B - x_I)\tan\alpha. \tag{1}$$

where points left from O are taken negative, φ the angle of incidence and α the angle of refraction. Here $x_B - x_S$ is the distance between the source and the surface and $x_B - x_I$ the distance between the image and the surface. Snell's law of refraction reads

$$\sin\alpha = n\sin\varphi. \tag{2}$$

For small angles ($\alpha, \varphi \ll 1$) Eqs. (1) and (2) reduce to

$$(x_B - x_S)\varphi = (x_B - x_I)\alpha \tag{3}$$

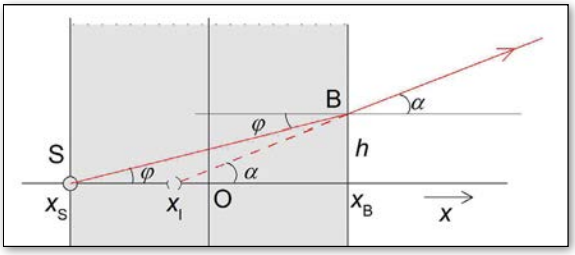
and

$$(x_B - x_S) = (x_B - x_I)n. \tag{4}$$

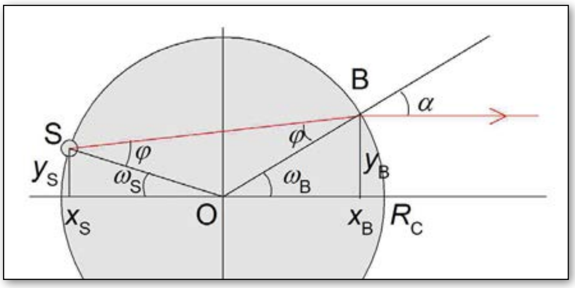
For $n \approx 4/3$ (water) we see that a diver or snorkeler, looking at the sea through his diving mask, observes fish 25% closer than they really are.

In our case the source is taped onto the back of a cylinder. With the origin at the axis $x_B = - x_S$ (see Fig. 5) and Eq. (4) with $n \approx 4/3$ yields $x_I \approx 0.50\, x_S$. As x_S and x_I are both negative the image is halfway between the origin and the back of the glass.

With a camera focused on this x_I the image of a point source is a small horizontal line. If the source is a horizontal wire, taped onto the cylinder of radius R_C, x_S varies from $-R_C$ to 0 so, in principle, x_I varies from $-0.50R_C$ to 0. However, as we will see later, only 23.5% from the back is visible so x_I is always close to $-0.5R_C$. Practically speaking, horizontal lines can be observed as sharp over the whole visible range of the source.



◂ **FIG. 4:** Image formation by rays in the vertical plane by flat surfaces. The positions of x_S and x_B in the case of a cylinder are indicated in FIG. 5.



◂ **FIG. 5:** Image formation by rays in the horizontal plane, with the observer at infinity.

Rays in the horizontal plane

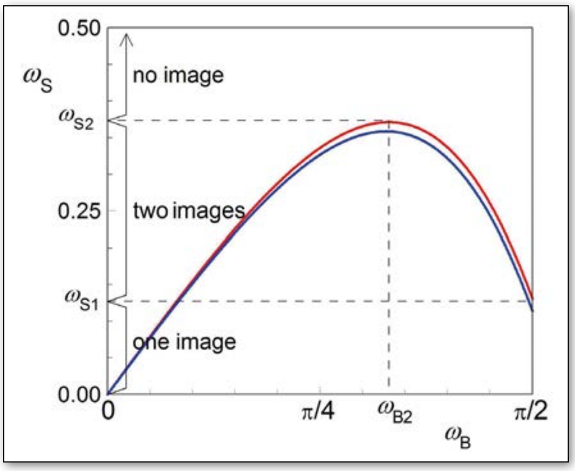
Next we consider the image formation in the horizontal plane. This corresponds to determining the position of the image of a vertical wire. The situation in which the observer is at infinity is depicted in Fig. 5. The angle of incidence φ is the angle between SB and the normal to the surface at B (*i.e.*, OB). Since $\omega_S + \omega_B = 2\varphi$ and $\alpha = \omega_B$, Eq. (2) reads

$$\sin\omega_B = n\sin((\omega_S + \omega_B)/2). \tag{5}$$

So

$$\omega_S = 2\arcsin((\sin\omega_B)/n) - \omega_B. \tag{6}$$

This relation is plotted in Fig. 6. For $\omega_B = 0$ we see that also $\omega_S = 0$, so source and image coincide. Rotating the cylinder clockwise means increasing ω_S. Initially ω_S and ω_B both increase. However, at $\omega_B = \omega_{B2}$, ω_S reaches a maximum ω_{S2}. From now on increasing ω_B decreases ω_S. For an image at the edge of the cylinder ($\omega_B = \pi/2$) the source is at ω_{S1}. For $0 < |\omega_S| < \omega_{S1}$ there is one image, for $\omega_{S1} < |\omega_S| < \omega_{S2}$ there are two solutions for ω_B so one source has two images. At $|\omega_S| = \omega_{S2}$ the two images coincide. For $|\omega_S| > \omega_{S2}$ there is no image: a wire in this region is invisible. For n = 1.33 we have $\omega_{B2} = 1.040$ rad, $\omega_{S1} = 0.131$ rad, and $\omega_{S2} = 0.371$ rad. So less than one quarter $(0.371/(\pi/2) = 0.236)$ of the back is visible through the glass.



◂ **FIG. 6:** ω_S as function of ω_B (Eq. (6)) for water for n = 1.33 (red light) and n = 1.34 (violet light). The ω_S-regions with one image, two images, and no image are indicated.

◂ FIG. 7: Picture of a tilted wire observed through a glass of water. The right-hand side of the curve is quite similar to the curve in FIG.6.

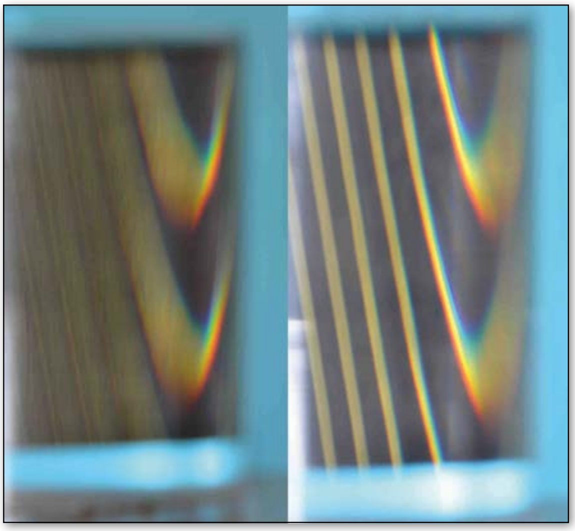
In Fig. 6 a curve is also drawn for violet light (n = 1.34). In this case ω_{S2} = 0.358 rad. A variation of n of 0.75% leads to a variation of ω_{S2} of 3.6%. So the values of the extrema are rather strong functions of n which explains the rainbow phenomena in Fig. 3.

Tilted wire

Instead of rotating the glass with a vertical wire we can also tape a slightly tilted wire onto the back of the glass. The vertical position is proportional to ω_S so we see the whole sequence of events in one glance (Fig. 7). The horizontal position is not proportional to ω_B but to sin ω_B, so the image is a somewhat distorted version of the curve of Fig. 6 but it shows the same features.

The x-positions of the images

The manual focus of a camera can be used to obtain a sharp picture of the vertical images as in Fig. 2. It turns out that the focus of the right image is in front of the glass, whereas the focus of the left image is behind it. If $\omega_S = \omega_{S2}$, where the two images coincide, one image is at $x_I = -\infty$ and the other at $+\infty$. This spectacular discontinuity is demonstrated in Fig. 8. The source is a slightly-tilted grating of yellow lines. In the left picture the focus of the camera is set in front of the glass and in the right picture far behind it. In both pictures the sharpness of the images has a pronounced discontinuity at the minima of the curves.



▸ FIG. 8: Photo of a tilted grid of yellow lines with the focus of the camera in front of the cylinder (left) and with the focus behind the cylinder (right).

If we use a point source at a position that gives two images ($\omega_{S1} < |\omega_S| < \omega_{S2}$) and increase the focal distance of the camera manually from zero to infinity we see the following sequence (apart from blurred images): first we see a sharp small vertical line segment on the right, next we see two small sharp horizontal lines, and finally we see one small sharp vertical line at the left. These phenomena can be understood using relatively simple geometrical optics but this is beyond the scope of this paper.

Discussion

The focus of rays in the horizontal plane is located inside the cylinder, about half a radius behind the cylinder axis and does not vary very much. By contrast, the focus of rays in the vertical plane is a strong function of the position of the source. In general, the distance between the focal planes of horizontal and vertical lines is typically a few times the diameter of the cylinder. As a result, a camera cannot take a photo in which all lines are sharp. Surprisingly enough this confusing situation does not result in a blurred image if the source is observed with the naked eye: one sees a perfectly sharp image even in monocular vision. For example, the pixels in the cheek of the cartoon of Fig. 1a can be seen very clearly. Apparently the human perception can handle this confusing information and construct a sharp image. How it manages to do that is a very interesting topic, but outside the scope of this paper.

Another interesting observation is the following: the drawing of Fig. 1a is taped onto the back of the glass, so it is evidently curved. However, if one looks at the cartoon through the glass of water the image is rather flat. Perhaps this is related to the fact that only the central 25% of the cartoon is visible, but it may also have to do with the way our eyes and brain handle the optical information. ■

About the author

Alphons (Fons) de Waele is emeritus professor of physics at Eindhoven University of Technology. His main interests are thermodynamics and, in particular, refrigeration technology. He has been director of education and has written several articles in Wikipedia.

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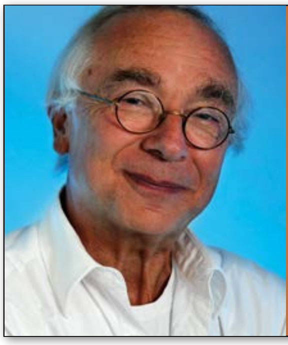


Opinion: An oral history

Herman Beijerinck – H.C.W.Beijerinck@kpnmail.nl – is an emeritus professor of physics at Eindhoven University of Technology

Students are well trained in analyzing the curriculum and their professors. Their ambition for understanding a subject is determined by the skills required to pass tests. Having to solve only standard problems at an exam results in learning by heart rather than in true problem-solving skills.

Content and personal skills

Seven years of teaching an introductory quantum mechanics course to bachelor students in their third year has been an interesting experience in the dynamics of testing students. The department had opted for an oral exam, to test students on a combination of both content and personal skills. At an early stage students are confronted with the strong tradition in physics to discuss all new developments in front of a white board. Visualizing new ideas in simple diagrams and discussing trends without doing the full math: these are the essential skills to be learned.

The ultimate aim in physics is to obtain insight, not routine skills. By choosing for an open-book exam and allowing the students to use a home-made, two-page compendium of 'important' information, the professor is forced to think of well-phrased and original problems. This is a challenge, but a nice one. By combining this approach with an oral final exam, we can really challenge our students to get to the core business of physics.

How it works

My exams were organized in a clockwork fashion: eight students in four hours of my time. Starting with two hours in splendid isolation with two problems (each containing five logical steps with increasing complexity), the student finally entered my office for a 30 minute oral exam. Grading their work was done while asking why certain – correct or incorrect – steps were taken. This additional information discriminates between 'lucky' correct answers, simple mistakes and lack of insight.

Then, simple pictograms were used to test their skills for, *e.g.*, drafting wave functions for atomic potential wells or the reflection and transmission at potential barriers. Without any math one can illustrate the trend in period and amplitude of a wave function, testing insight instead of rote problem-solving. Moreover, the students were asked to support their drawing activities by telling their line of thought.

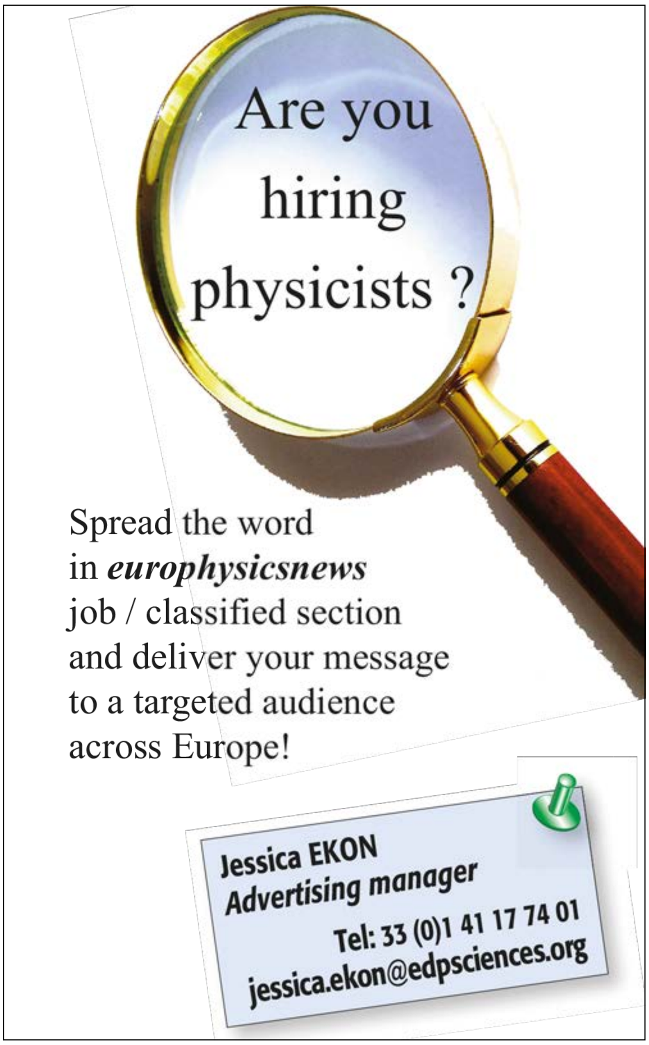
Throughout seven years I have used the same two sets of two problems for the written part. Although the students were not allowed to keep the problem sheet, I was highly surprised that underground editions of these problems never emerged. Moreover, the statistics of the results obtained never shifted in these seven years. As training material, a set of 20 problems was available, so the type of problem was no surprise. If a student failed, the skills to tackle a new problem had simply not been acquired.

Positive long-term effect

This exam was considered the most difficult to pass. Students hated me for my exams! However, at a later stage, during their M.Sc. and PhD programs, they confessed that my course was one of the few where they really learned about physics and about hard work. The department hated me for delaying the progress of students, creating a back log of unfinished business. However, they also appreciated very much the positive long-term effect on the students.

Of course, not all courses can be tested in this way. Nevertheless it is good to have such a stumbling stone once in a while. A controlled stumble can be very useful to learn to walk in a more self-confident way, with a better academic balance as the final result.■

The ultimate aim in physics is to obtain insight, not routine skills.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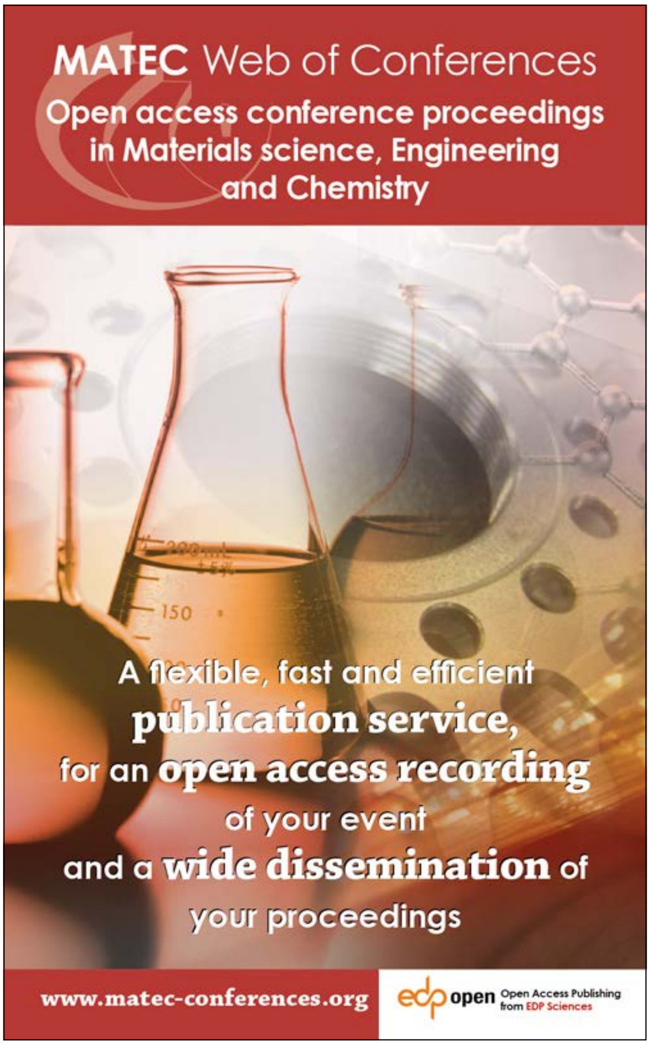
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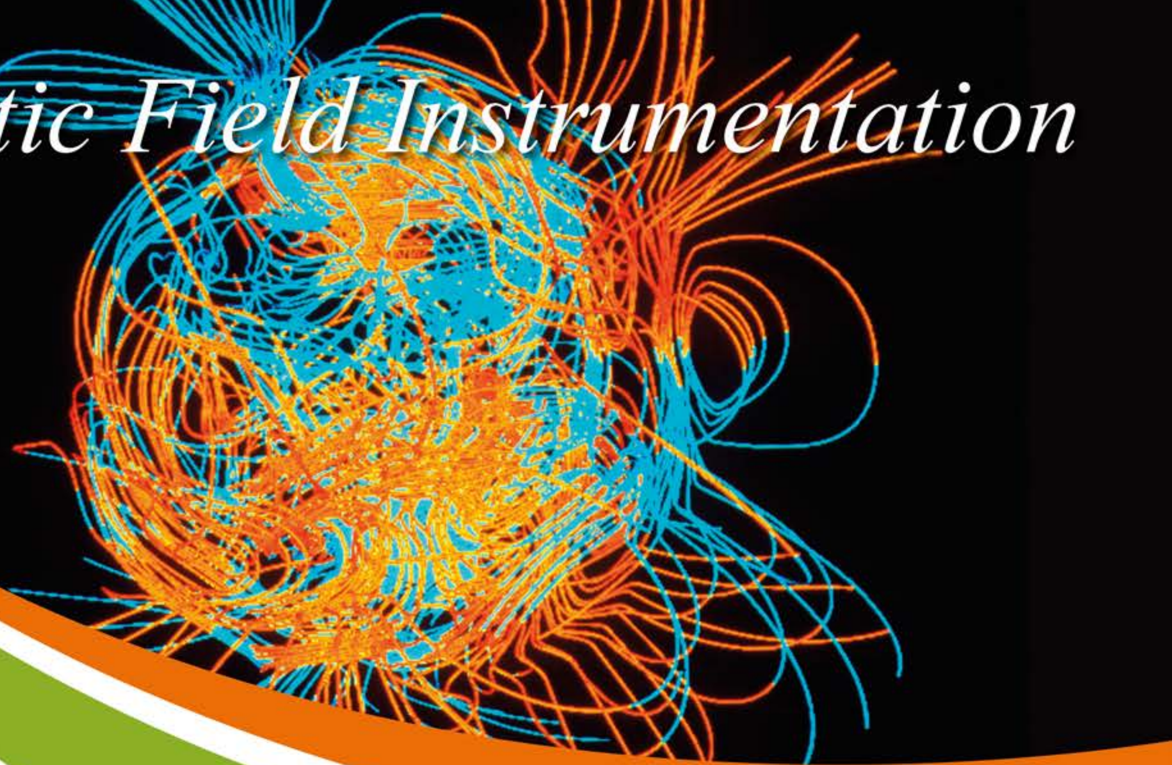

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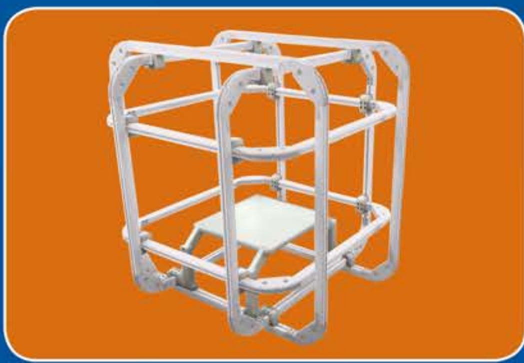

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