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Laureates of several 2011 EPS prizes
The 'French Blue' diamond
Ratchets from the cold
A new spin on Earth's deep mantle
Lyrics about Physics

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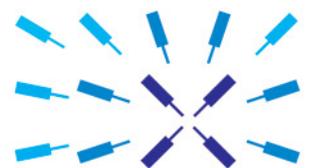
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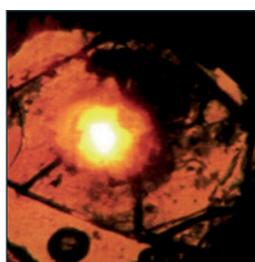
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Cover picture: Diamond anvil: facets and experimental table. The diamond anvil press reproduces the extreme conditions that exist in the earth mantle.
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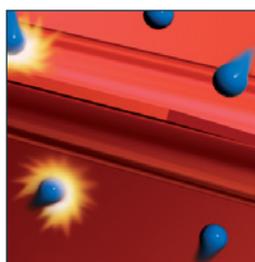
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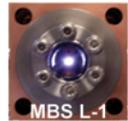
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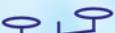
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The EPS strategy plan 2010+ in full development

It is time to take stock of the first achievements of the Society according to the EPS Strategy Plan 2010+, adopted by Council 2011.

Many actions of the EPS as a '*federation*' of European national societies have been undertaken, such as the ASEPS2 transnational summit in Poland, the launch of the International Year of Light initiative which is likely to be soon approved by UNESCO, the start of a dedicated study on 'Physics and the European economy' that will be presented by the end of this year, etc.

The EPS has been active in responding to various EC consultations, for instance the ERA Framework Public Consultation on 'Areas of untapped potential for the development of the European Research Area', or the consultation on the Green Paper: 'Towards a Common Strategic Framework for EU research and innovation funding', or the one on 'Access to and preservation of digital information'.

Contacts with the ERA representatives have also been established, as well as with representatives of the OECD Global Science Forum.

I am also glad to inform you that I have recently been elected member-at-large of the Forum on International Physics of the American Physical Society (APS) and appointed member of the APS Committee on International Scientific Affairs. This is for me a great honour and it will indeed help in the promotion of many of our common objectives.

For the EPS activities as a '*learned society*', we are of course very proud of our e-bulletin, started in May 2011, which is now becoming rather popular.

Also a brand new EPS web site has just been released, with new structure, layout, contents, facilities, etc. and we strongly encourage our members/readers to send us comments and suggestions for future improvement. The number of EPS Individual Members (and of Associate Members) has been increasing and I cannot but warmly invite our readers to subscribe. The EPS Divisions/Groups conferences and prizes have been outstanding, the EPS Historic Site programme has started, with the creation of the first one in Warsaw (on the occasion of the Marie Curie celebrations in 2011). The revival of the Technology Group has been achieved with its transformation into - as the sign of times - a Technology and Innovation Group (TIG) and a founding TIG workshop is already foreseen in mid-summer this year.

In 2012 energy will be on stage with the second European Energy Conference of Maastricht (NL) and with the first course of the Joint EPS-SIF International School on Energy in Varenna (IT).

Finally a conference on Physics for Development at ICTP is taking shape, as well as a very interesting session of our EPS Forum on Physics and Society, focused on 'Physics and the marketplace'.

The EPS Strategy Plan 2010+ is being pursued, thanks to all. Let's go on.

■ **Luisa Cifarelli**
President of the EPS

Report on the Balkan School and Workshop 2011

School on Cosmology and Particle Physics beyond the Standard Models

The Balkan School 2011 for MSc and PhD students, held in Donji Milanovac, SERBIA, from 21 – 27 August 2011 was one of the core meetings of the South-Eastern European Network in Mathematical and Theoretical Physics (SEENET-MTP, www.seenet-mtp.info).

The goal of the BS2011 School was to improve the students' and young researchers' knowledge in the scientific fields of the event, *i.e.* Cosmology, Particle Physics and some aspects of Astrophysics. The BS2011 School gathered six renowned experts as lecturers (Fred Adams (Michigan), Ignatios Antoniadis (CERN), Tao Han (Wisconsin), Neil Lambert (CERN), Viatcheslav Mukhanov (Munich) and Goran Senjanović (ICTP)), two tutors (Miha Nemevšek (ICTP) and Alexander Vikman (CERN)) and 50 students, mostly from Europe. An introduction and a summary were given by Goran Djordjević (Niš). 17 countries were represented and Four EPS grants were distributed.

The lecturers started from an introductory level to gradually approach an advanced research level. All lectures were followed by discussions, while those given by V. Mukhanov and G. Senjanovic benefited from additional tutorials/exercises by M. Nemevsek and A. Vikman.

Prof. T. Han, USA, was not able to attend, his flight being cancelled by an earthquake. A video link between Prof. Han and the participants was then organized at the end of the School, and a short lecture about Collider Physics was nevertheless provided.

The high level of the lecturers, *i.e.* lectures and tutorials, as well as the optimised number of excellent students made this School one of the best in the Balkan region ever and will highly contribute to improvement

of students' knowledge and research activities.

Workshop on Particle Physics from TeV to Planck Scale

This Balkan Workshop 2011 was held in Donji Milanovac, SERBIA, from 27 August to 1st September 2011 in the frame of the South-Eastern European Network in Mathematical and Theoretical Physics (SEENET-MTP). There were 73 attendees and 4 EPS grants attributed.

The main idea of the Balkan Workshops (the 4th one in the SEENET-MTP series, started in 2003) - as well as of the whole Network, is to create a sustainable framework for the researchers active in Theoretical and Mathematical Physics, first of all with a focus on high energy physics and cosmology at different institutions in South-East Europe and to showcase their work and results as well as to exchange ideas with colleagues from the region, Europe and all over the world. 15 (out of 26) invited speakers came from outside the region. Leaders in their fields, they provided a very high level of scientific excellence. The topics were: Dark Matter (connecting micro- and macro-Cosmos), LHC Experiments, Theory and Phenomenology, Supersymmetry, String Theory and Phenomenology, Cosmology and Planck Scale Physics, numerical simulation in Astrophysics and other. It gave a great opportunity to younger attendees from the region

to put in perspective their own investigations. It is evident that there are more and more joint papers of the local researchers, as well as first applications for joint project in some particular field of HEP research.

This School was one of the best in the Balkan region ever.

The first two days of the meeting were devoted to the scientific and human legacy of Prof. Dr. Julius Wess. The scientific part consisted of six lectures on different aspects of algebraic deformations, non-commutative geometry and physics. The Workshop was opened by "Minimal Inflation" talk of L. Alvarez Gaume, where MI was based entirely on the general properties of supersymmetry breaking in supergravity models. G. Martinelli reviewed possibilities to detect physics beyond Standard Model in B-physics sector. S. Sekmen (CMS) and T. Kono (ATLAS) presented the latest results and ongoing experiments and technical constraint of their corresponding detectors at LHC. Despite the fact that DM particles are not detected yet both lectures were great opportunities for a number of researchers and advance students to get a good insight in the current research of both collaborations. G. Senjanovic concentrated on theoretical and experimental signatures of neutrinos being Majorana particles.

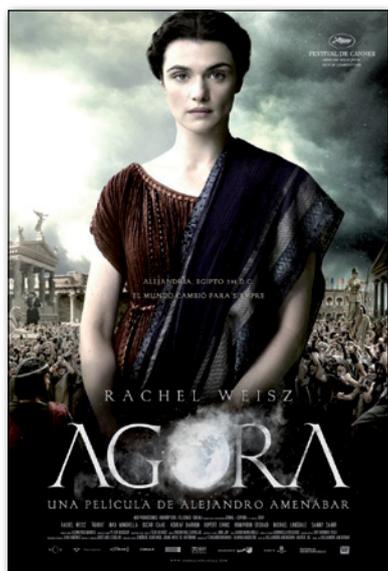
Selected papers related to 36 invited lectures and a number of poster presentations will be published in a special volume of the Romanian Journal of Physics, as well as in a special volume of IJMP CS. ■

Unusual award in Spain to the film director Alejandro Amenábar

The Royal Spanish Physical Society recognizes the film writer and director Alejandro Amenábar for his movie on a famous 4th century female scientist: Hypatia de Alexandria.

The Governing Board of the Royal Spanish Physical Society, meeting on 10 July 2011, decided to recognize the film director Alejandro Amenábar for “his services to Science in a general public movie, illustrating the rationality of the scientific knowledge and showing rigorous and well-explained experiments while portraying the life of a unique female scientist (and philosopher): Hypatia of Alexandria”.

Alejandro Amenábar is a Spanish movie writer and director who won, among other prizes, the 2005 Academy Award (Oscar) for Best Foreign Language Film for his movie



Mar Adentro (The Sea inside). Other movies written and directed by him include The Others (2001, with Nicole Kidman) and Agora (2009, with Rachel Weisz). Agora is a biopic based on the life of Hypatia of Alexandria, a female mathematician, philosopher and astronomer in 4th century Roman Egypt who investigated the flaws of the geocentric Ptolemaic system and the heliocentric model that challenges it. Surrounded by religious turmoil and social unrest, Hypatia struggled to save the knowledge of classical antiquity from destruction. She was the daughter of the mathematician Theon Alexandricus, the last librarian of the Library of Alexandria. After studies at Athens and in Italy, she started teaching philosophy as head of the Platonist school at Alexandria, to any local or foreign student, being pagans or Christians. Five years later, in 405, a conflict arose between the Christian bishop Cyril and the prefect Orestes, a pagan as his friend Hypatia. She was accused of having started the conflict and wildly killed in the street by a group of fanatics. She had written a “Commentary on the Arithmetica of Diophantus” and a “Commentary on the Conics of Apollonius”.



▲ The film writer and director Alejandro Amenábar (left) receives a certificate of recognition from the Royal Spanish Physical Society represented by the President, María Rosario Heras (right). Santander, 22 September 2011.

On 22 September 2011, Alejandro Amenábar attended a Special Session during the 33rd Biannual Meeting of The Royal Spanish Physical Society (RSEF) that took place in Santander (Northern Spain). He received an engraved plaque presented by the President of the RSEF, María Rosario Heras, as sign of recognition. He said: “I have received many awards and recognitions during my life, but this particular one I appreciate very much because it comes from a Learned Society. It demonstrates that movies can also educate and not just entertain”. This event got significant coverage in Spanish newspapers and Radio and TV news.

◀ The original poster of the movie

■ José M. Ortiz de Zarate,
Universidad Complutense de Madrid
and Royal Spanish Physical Society

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Laureates of several 2011 EPS prizes

THE EPS PLASMA PHYSICS DIVISION (PPD) 2011 PRIZES

At their annual Conference, held from June 27 – July 1 2011 in Strasbourg (FR), the EPS Plasma Physics Division rewarded researchers who have achieved outstanding scientific or technological results. In this way, the EPS PPD wants to reinforce excellence in science.

The EPS Hannes Alfvén Prize 2011

This divisional Prize is awarded to (alphabetic order):

- **Patrick Diamond** (University of California, United States of America; National Fusion Research Institute, Korea),
- **Akira Hasegawa** (Osaka University, Japan),
- **Kunioki Mima** (Graduate School for the Creation of New Photonics Industries at Kamamatsu, Shizuoka, Japan),

"for laying the foundations of modern numerical transport simulations and key contributions on self-generated zonal flows and flow shear decorrelation mechanisms which form the basis of modern turbulence in plasmas".

Confined thermonuclear plasma is far from equilibrium due to strong external drives that maintain steep gradients in the plasma parameters. The heat and particle transport in fusion plasmas is generally due to turbulent processes associated with small-scale instabilities driven by the inhomogeneity of density and temperature profiles in the direction normal to the magnetic surfaces.



▲ Left to right: K. Sakamoto, A. Litvak and MKA Thumm

▼ Left to right: P. Diamond, A. Hasegawa and K. Mima

The magnitude of turbulent transport is probably the dominant parameter affecting the global confinement properties and hence the understanding of turbulence is a fundamental issue for the success of controlled magnetic nuclear fusion. A. Hasegawa and K. Mima developed the model equation (the Hasegawa-Mima-Wakatani equations) predicting the development of inverse cascade of turbulent energy spectra and condensation of the spectrum to form zonal flows in the azimuthal direction which can control turbulent radial diffusion. P. Diamond's contributions led to paradigm shifts on turbulent transport including the self-generation of zonal flows as a crucial element of turbulent transport, the shear decorrelation mechanisms and predictions based on predator-prey models of plasma bifurcations. Their predictions have already been partially confirmed by experiments carried out in tokamak and stellarator devices and provide the basis for the development of predicting capability of transport in future fusion devices. The award of the 2011 Hannes Alfvén Prize to these three leading scientists underlines the importance of their ideas as the most influential in the area of turbulence and transport in magnetically confined plasmas and in the transfer of knowledge in plasma physics.

The EPS Plasma Physics Innovation Prize 2011

This prize is awarded to (alphabetic order):

- **Alexander Litvak** (Nizhny Novgorod, Institute of Applied Physics of Russian Academy of Sciences, Russia),
- **Keishi Sakamoto** (Naka, Japan Atomic Energy Agency, Japan),
- **Manfred Kaspar Andreas Thumm** (Karlsruhe Institute of Technology, Germany),

"for outstanding contributions to the realization of high power gyrotron for multi-megawatt long-pulse electron cyclotron heating and current drive on magnetic confinement nuclear plasma devices".

The electron-cyclotron method of plasma heating and current drive has shown its efficiency in numerous experiments at large scale magnetic fusion experiments. The modern wave systems are based on gyrotrons, the most powerful sources of coherent radiation in the millimeter wavelength range, capable to generate radiation with a megawatt power level in long-pulse regimes. The three teams led by A. Litvak, K. Sakamoto and M. Thumm, together with a successful international collaboration, have provided outstanding contributions in the theoretical and experimental research and innovation on high

power long pulse gyrotrons. The European Physical Society bestows its 2011 Plasma Physics Innovation Prize for all of these outstanding developments in high power sources of coherent microwaves.

The EPS-PPD PhD Research Award 2011

This Award has been recently judged by a committee comprising of Juergen Nuehnenberg, Uwe Czarnetzki and Jean-Claude Gauthier, who examined all the candidatures in a process managed by Dimitri Batani. The EPS PhD prize is a key element of the EPS PPD activities to recognise the exceptional quality of the work carried out by young scientists. Based on their conclusions, and considering the diversity of top PhD research work in different plasma physics areas, a decision was made to award the EPS-2011 PhD Award to (alphabetic order):

- **Stefan Kneip** (Imperial College, UK)
"for the investigation of laser generation

of x-rays, including the study of electron acceleration in the bubble regime and experimental demonstration of self-guiding",

- **Julian Schulze** (Ruhr-University Bochum, Germany)
"for his research on electron heating in capacitively coupled radio frequency discharges, including contributions on electrical asymmetry effects affecting ion energy distribution",

▼ Left to right:
J. Schulze,
M. Schwabe
and S. Kneip

- **Mierk Schwabe** (Max-Planck Institute for Extraterrestrial Physics, Germany)
"for her research on dynamical effects in complex plasmas to study phenomena ordinarily described by fluid dynamics at the level of individual particles".

■ **Carlos Hidalgo**,
chair EPS Plasma
Physics Division



EPS ACCELERATORS GROUP 2011 PRIZES

The EPS Accelerators Group announces the winners of the following prizes, which have been given at the International Particle Accelerators Conference 2011 (IPAC 11) held in San Sebastian (SP) 4-9 September 2011 - www.ipac-2011.org/inicio.asp :

The **Rolf Wideroe Prize** for outstanding work in the accelerator field to **Shin-ichi Kurokawa**, KEK.
"For outstanding leadership in the design, construction and operation of several high-energy accelerators, including the KEK PS, TRISTAN and the KEK B-Factor. Through his intensive participation in the international collaboration within ACFA and ICFA, he initiated and expanded worldwide scientific exchange, building sturdy bridges of understanding and collaboration between Japan, Asia and the rest of the world".

The **Gersh Budker Prize** for a recent, significant contribution to the accelerator field to **Yasushige Yano**, RIKEN.

"For his innovation and leadership in the design, construction and successful operation of RIBF, the world's first radioactive ion beam facility based on SC sector-magnet cyclotrons. Dr. Yano's understanding and foresight have led to major advances in cyclotron technology and in realizing them he has created a major new facility for nuclear physics with unparalleled capabilities for years to come".

▼ Left to right:
S.I. Kurokawa,
Y. Yano and
R. Tomas Garcia



The **Frank Sacherer Prize** for an individual in the early part of his or her career, having made a recent significant, original contribution to the accelerator field to **Rogelio Tomas Garcia**, CERN.

"For his many important, original contributions to accelerator physics, especially the optics design and optics measurement and correction techniques applied to a large number of circular and linear collider projects. Dr. Tomas' achievements combine theoretical ability with practical skills, and range from studies of resonances and non-linearities in accelerators and beam lines to operations and upgrades for the LHC".

More information on EPS AG Prizes can be found at:

http://epac.web.cern.ch/EPAC/EPS-AG/Accelerator_Prizes/EPS-AG_Prize_Winners.htm

THE EPS HIGH ENERGY PHYSICS DIVISION PRIZES 2011

The **2011 High Energy and Particle Physics Prize** for an outstanding contribution to High Energy Physics in experimental, theoretical or technological area is awarded to **Sheldon Lee Glashow, John Iliopoulos and Luciano Maiani**,

"For their crucial contribution to the theory of flavour, presently embedded in the Standard Theory of strong and electroweak interactions."



◀ L. Maiani and S.L. Glashow

The **2011 Young Physicist Prize** for outstanding work by one or more early career physicists in the field of Particle Physics and/or Particle Astrophysics is awarded to **Paolo Creminelli**,

"For his contributions to the development of a solid field-theoretical approach to early-universe cosmology"



◀ P. Creminelli and A. Rizzi

*and for his studies of non-gaussianities in the cosmic microwave background"; and to **Andrea Rizzi***

"For his contributions to the reconstruction software and physics programme of the CMS experiment at the LHC".

The **2011 Gribov Medal** for outstanding work by an early career physicist in Theoretical Particle Physics and/or Field Theory is awarded to **Davide Gaiotto**,

"For the uncovering of new facets of the dynamics of four-dimensional supersymmetric gauge theories. In particular,



▶ D. Gaiotto

for discovering a large class of four-dimensional superconformal theories and for finding with others important intricate relations between two-dimensional theories of gravity and four-dimensional gauge theories".

The **2011 Outreach Prize** for outstanding outreach achievement connected with High Energy Physics and/or Particle Astrophysics is awarded to **Christine Kourkoumelis and Sofoklis Sotiriou**,

"For building educational resources to bring the research process in particle physics and its results to



▲ C. Kourkoumelis and S. Sotiriou

teachers and students, both nationally and across Europe"

The **2011 Giuseppe and Vanna Cocconi Prize** for an outstanding contribution (experimental or theoretical) to Particle Astrophysics and Cosmology to **Paolo de Bernardis and Paul Richards**,

"For their outstanding contributions to the study of cosmic microwave background anisotropies with the balloon-borne experiments BOOMERanG and MAXIMA".

For information on the EPS-HEPP Division prizes, please see:
<http://eps-hepp.web.cern.ch/eps-hepp/prizes.php>

▼ P. de Bernardis and P. Richards



THE EPS LIQUID MATTER PRIZE 2011 [REMINDER, SEE EPN 42/1 P.10]

David Chandler, University of California, Berkeley received this prize at the 8th EPS Liquid Matter Conference, 6-10 Sept., 2011, in Vienna, Austria <http://lmc2011.univie.ac.at>. These triennial conferences bring together scientists working on all aspects of the liquid state including soft matter and biophysics. Previous awardees were J-P. Hansen (2005) and H.N.W. Lekkerkerker and P.N. Pusey (2008).

Chandler, one of the leading liquid matter theorists world-wide, is recognized *"for seminal works that have enhanced our understanding*



▶ D. Chandler

of the molecular nature of liquid matter, including highly original and influential theories of

microscopic structure, chemical equilibrium and kinetics, quantum processes in fluids, hydrophobicity and vitrification".

The full note on David Chandler, written by C. Dellago, Chair EPS Liquids Board, and R. Evans, Chair Prize Committee, can be found in:
<http://lmc2011.univie.ac.at/liquid-matter-prize/>

IBA PRIZE 2011 OF THE NUCLEAR PHYSICS DIVISION

The EPS Nuclear Physics Division has announced the winner of the 2011 IBA Prize at the first International Conference on Advances in Radioactive Isotope Science (ARIS), held in Leuven, (BE), May 29 to June 3, 2011.



◀ E.Boaretto

More information on the event in:
<https://iks32.fys.kuleuven.be/indico/conferenceDisplay.py?confId=0>
 This Prize for Applied Nuclear Science and Nuclear Methods in Medicine is awarded to Dr **Elisabetta Boaretto** (Radiocarbon Dating and Cosmogenic Isotopes Lab, Bar Ilan University, Israel, and Kimmel Center for Archaeological Science, Weizmann Institute of Science,

Rehovot, Israel) "*In recognition of her significant contribution to the development of precise quality controlled radiocarbon dating and the application of accelerator mass spectrometry techniques to the field of archaeology*".

More information on the laureate, her work and other EPS NPD Prizes can be found here:

<http://nuclear.epsdivisions.org/>

Proposal to increase Individual Membership Fees

To be presented to EPS Council 30-31 March 2012

The Executive Committee has decided to propose to the EPS Council Meeting on 30-31 March 2012 to increase the membership fees for EPS Individual Members. Fees for Individual Members have not been increased since 2007. Over the period 2007-2011, the cumulative inflation rate is over 11%. Any increase decided by Council 2012 will not take effect until 2013.

The proposal would increase EPS Individual Membership fees as follows:

- Individual Member Category 3a Euro 20 would be increased to Euro 22

▼ TABLE: Units for the various Individual Member categories

Categories	Member	Units
3.3 a)	Full	2,2
	Below 30 years of age	1,65
	Retired	1,65
	Teachers/Students	1,65
3.3 b)	Full	4,4
	Below 30 years of age	2,2
	Retired	2,2
	Teachers/Students	1,65
3.3 c)	Full	6,6
	Below 30 years of age	3,3
	Retired	3,3
3.3 d)	Student	1,65
3.3 e)	Teacher	1,65

- Individual Member Category 3b Euro 40 would be increased to Euro 44
- Individual Member Category 3c Euro 60 would be increased to Euro 66
- Individual Member Category 3d Euro 15 would be increased to Euro 16,50
- Individual Member Category 3e Euro 15 would be increased to Euro 16,50

Amendment

According to §5 of Annexe 1 to the Constitution and By-laws, the Unit Fee for the Calculation Individual Membership fees is fixed at Euro 10.

The Executive Committee proposes to modify section 6 of Annexe 1 to the Constitution and By-laws as follows: "§6 Membership fee of Individual Members: The membership fee for members according to Art.3 a) ... e) is calculated as the average unit fee multiplied by the number of units given in the table"

Effect

The amendment would be applicable for Individual Membership fees invoiced for the year beginning 1 January 2013. No other provision of the Constitution is hereby modified.

COMING EPS EVENTS

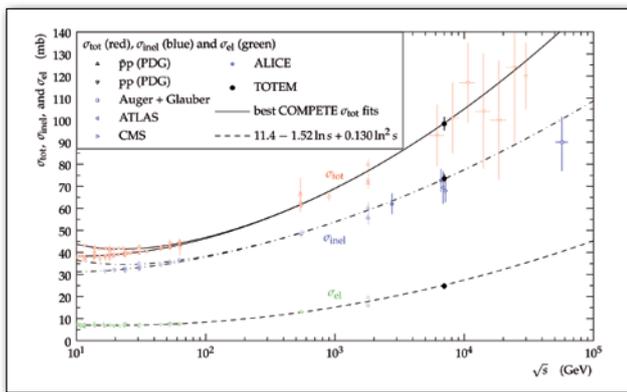
- **Forum Physics and Society**
28-29 March 2012, CERN, Geneva
- **Council Meeting**
30-31 March 2012, CERN, Geneva
- **ICN+T 2012**, International Conference on Nanoscience + Technology
23-27 July 2012, Paris, France
www.icnt2012.fr
- **UP2012**
XVIIIth International Conference on Ultrafast Phenomena
9-13 July 2012, Lausanne, Switzerland
www.up2012.org
- **EUROPHOTON 2012**
26-31 August 2012, Stockholm, Sweden
www.europhoton.org
- **MORE ON:**
www.eps.org

Highlights from European journals

PARTICLE PHYSICS

A LHC first: proton-proton cross-section at 7 TeV

The proton, one of the basic building blocks of the atomic nuclei, is a dynamic and complex system: its sub-components and their interactions keep it together in a very dynamic way. The inner structure of protons can be studied by observing how they interact with each other, which implies measuring the total cross-section of the proton-proton interactions. To measure it, the TOTEM experiment uses the fact that the total cross-section can be related to the elastic forward scattering amplitude.



▲ The TOTEM measurement of the total cross-section of the proton at the 7 TeV centre-of-mass energy of 98 ± 3 mbarn is shown together with results from previous measurements and from cosmic rays.

Due to the tiny scattering angles the protons have to be measured very close to the CERN LHC beams, requiring custom-designed silicon detectors with full efficiency up to the physical edge. The measurement was performed in a dedicated run with special beam optics that made the angular beam spread in the interaction point small compared to the scattering angles.

The TOTEM experiment has confirmed the increase with energy of the proton-proton total cross-section by a (98 ± 3) mbarn result at the so far unexplored energy of the LHC. This phenomenon was expected from previous measurements performed at energies 100 times smaller at the CERN ISR in 1972. It is remarkable that the early indirect cosmic ray measurements are in good agreement with the new precise TOTEM value. ■

■ **The TOTEM collaboration: G. Antchev *et al.***
(73 co-authors),

'First measurement of the total proton-proton cross section at the LHC energy of $\sqrt{s}=7$ TeV', *EPL* **96**, 21002 (2011)

APPLIED PHYSICS

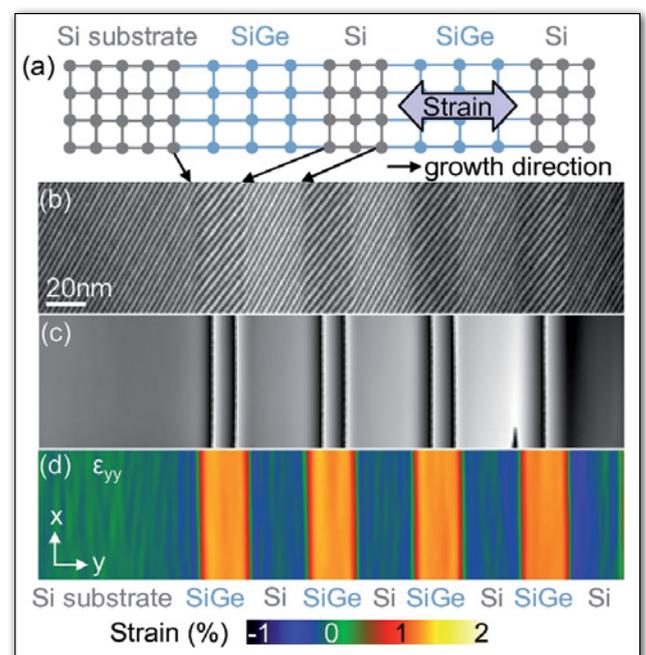
Quantitative strain mapping at the nanometer scale

As strain is now used routinely in transistor devices to increase the mobility of the charge carriers, the microelectronics industry needs ways to map the strain with nanometer resolution. Recently, a powerful TEM (transmission electron microscopy) based technique called dark-field electron holography has been invented by Martin Hÿtch at CEMES in Toulouse. To map the strain, it is necessary to thin a sample to electron transparency using a focused ion beam tool. Then, to form a dark-field electron hologram, electron beams that have been diffracted by both the region of interest (a device, a layer) and a region of reference (usually the substrate) are interfered using an electron biprism.

When grown on a Si substrate by epitaxy, SiGe layers are tensile strained in the growth direction as shown in Figure (a). Due to the presence of strain, variations of the hologram fringe spacing can be seen (b). Using Fourier space processing, the phase of the electrons can be retrieved from the hologram (c), and by taking the gradient of the phase, the strain map can then be calculated (d).

As the technique is quantitative, one can directly correlate the results with simulations to get information about the composition in the layers. As an example, we have investigated the

▼ (a) Scheme and (b) dark-field (004) electron hologram of a Si/Si_{0.79}Ge_{0.21} superlattice. (c) Phase of the hologram. (d) Strain map.



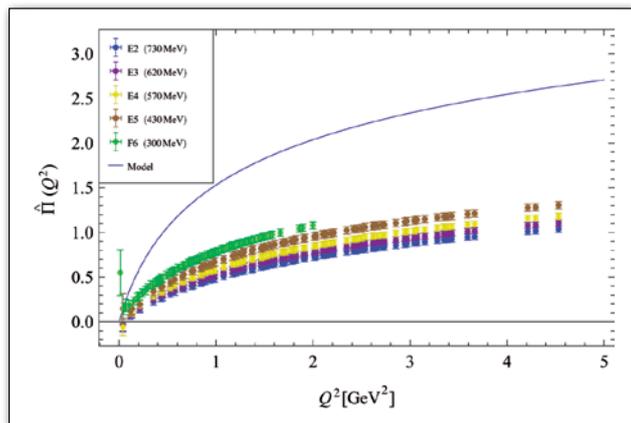
variation of the substitutional carbon content in annealed Si/SiGeC superlattices. Carbon is used to control the strain and avoid plastic relaxation. However during annealing, the formation of β -SiC clusters reduces the effect of the C atoms. By combining holography and finite element simulation, we have shown that after annealing at 1050°C, a SiGeC structure behaves like pure SiGe from the point of view of strain.

■ **T. Denneulin, J.L. Rouvière, A. Béch , M. Py, J.P. Barnes, N. Rochat, J.M. Hartmann and D. Cooper,** 'The reduction of the substitutional C content in annealed Si/SiGeC superlattices studied by dark-field electron holography', *Semicond. Sci. Technol.* **26**, 125010 (2011)

PARTICLE PHYSICS

Vector correlators in lattice QCD

Vacuum polarisation, the modification of the photon propagator due to virtual electron-positron pairs, is one of the first quantum loop corrections encountered in field theory. In both QED and QCD it causes the running of the appropriate fine structure constant as the physical scale is varied, and also corrects the magnetic moments of electrons and muons from the value 2 predicted by the Dirac equation. For scales below a few GeV the QCD vacuum polarisation cannot be calculated perturbatively, but can be accessed via the optical theorem from the annihilation cross section of e^+e^- into hadrons, which is simply related to the spectral density $\rho(s)$ in the vector isoscalar channel.



▲ Comparison of the vacuum polarisation calculated from e^+e^- annihilation cross section with recent lattice simulations.

This paper opens a new direction by first assessing the current state-of-the-art in calculating the vacuum polarisation in lattice QCD, the most systematic non-perturbative approach, and then by setting out two different routes to improving on this, and identifying applications to strong interaction phenomenology. Comparison with experimental data reveals that current results are badly finite-volume affected. The paper provides technical

details enabling these distortions to be understood and ultimately extrapolated to the large volume limit. It also uses the same data to estimate the current-current correlator as a function of Euclidean time exposing the possibility that different ranges are amenable to different theoretical approaches; the dominant hadronic correction to $(g-2)$ for the muon, about to be measured with unprecedented precision at Fermilab, comes from the range $0.5\text{fm} < ct < 1.5\text{fm}$. This reasoning is also suggests a new QCD reference scale, to help calibrate the lattice spacing using high-precision numerical estimates of the vector correlator.

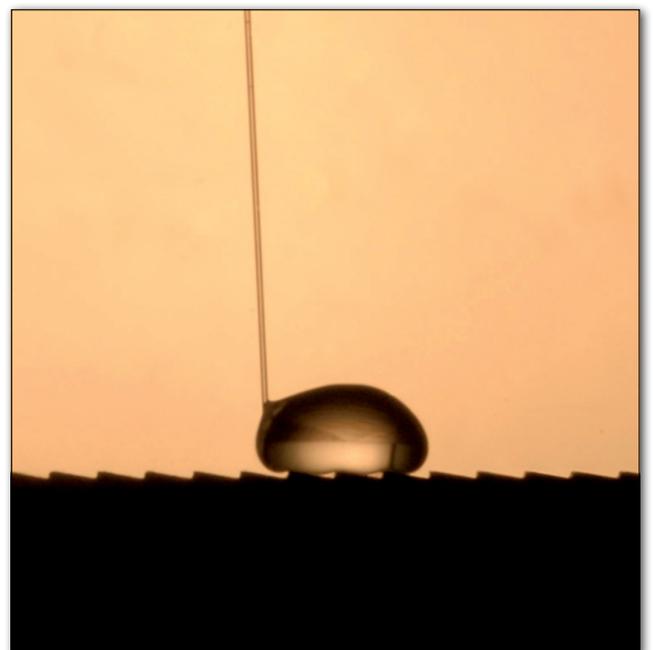
■ **D. Bernecker and H. Meyer,** 'Vector Correlators in Lattice QCD: Methods and Applications', *Eur. Phys. J. A* **47/11**, 1 (2011)

MATERIAL SCIENCE

Leidenfrost propulsion on a ratchet

The Leidenfrost phenomenon is observed when depositing liquids on solids much hotter than their boiling point. Liquids then levitate on a cushion of their own vapour, and slowly evaporate without boiling, due to the absence of contact with the substrate. The vapour cushion also makes liquids ultra-mobile, and Linke discovered in 2006 that Leidenfrost drops on a hot ratchet self-propel, in the direction of "climbing" the teeth steps. The corresponding forces were found to be 10 to 100 μN , much smaller than the liquid weight, yet enough to generate velocities of order 10 cm/s.

▼ Levitating Leidenfrost drop on a hot ratchet: a force acts on the drop, which deflects a fiber plunging in it.



The origin of the motion was not really clear, despite stimulating propositions in Linke's original paper. As a first step, it was reported in 2011 by Lagubeau *et al.* that disks of sublimating dry ice also levitate and self-propel on hot ratchets: liquid deformations are not responsible for the motion. However, the levitating object in all these experiments squeezes the vapour below, and the resulting flow might be rectified by the asymmetric profile of the ratchet. The key question was not only to check this assumption, but also to determine in which privileged direction the vapour flows. By tracking tiny glass beads in the vapour, it was shown that rectification indeed takes place, along the descending slope of the teeth – the vapour escaping laterally once reaching the step of the teeth. Hence the levitating body is entrained by the viscous drag arising from this directional vapour flow. Goldstein *et al.* reached a similar conclusion in a paper to appear in the *Journal of Fluid Mechanics*. Many questions however remain: ratchets also generate special frictions (the liquid hits the teeth as it progresses), and the optimal ratchet (maximizing the speed of these little hovercrafts) has not yet been designed.

■ **G. Dupeux, M. Le Merrer, G. Lagubeau, C. Clanet, S. Hardt and D. Quéré,**

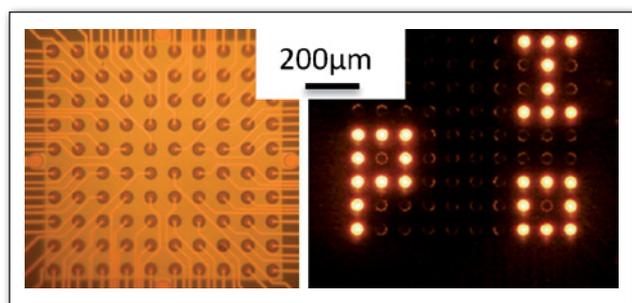
'Viscous mechanism for Leidenfrost propulsion on a ratchet', *EPL* **96**, 58001 (2011)

APPLIED PHYSICS

Yellow-green and amber InGaN micro-LED arrays

Longer wavelength InGaN emitters (~600nm) are important for some potential applications such as optoelectronic tweezers and visible light communication. The primary obstacle for developing InGaN light-emitting diodes (LEDs) at longer wavelengths, however, is because it is difficult to incorporate a high indium composition (for extending the emission wavelength) while maintaining good epitaxial quality. Indium in high proportion tends to aggregate. High indium InGaN structures also show strong piezoelectric fields, which in turn induce a reduced wavefunction overlap between electrons and holes, and a consequently weakened emission. To overcome these effects, new epitaxial InGaN structures of high-indium content

▼ Representative amber micro-LED array and controllable emission pattern.



are grown, in which an electron reservoir layer is introduced to enhance the indium incorporation and the light emission, but retain conventional (1000) orientation.

Photoluminescence measurements reveal that the emission wavelengths of these high-In quantum well structures can be tuned from 560nm to 600nm, depending on actual indium composition. Yellow-green and amber devices in an array-format are developed based on these wafer structures, where each LED pixel can be individually addressable. Power measurements indicate that the power density of the yellow-green (amber) device per pixel is up to 8W/cm² (4.4 W/cm²), much higher than that of conventional broad-sized LEDs made under the same condition, and nearly an order higher than that required by optoelectronic tweezers, validating the feasibility of using these micro-LEDs for tweezing. Nevertheless, it is found that the emission wavelength is strongly blueshifted upon injection current increase, up to ~50nm. Numerical simulations reveal that this is caused by screening of the quantum Stark effect and a band filling effect, thus further optimisation of the growth conditions and epitaxial structures is needed.

■ **Z. Gong, N.Y. Liu, Y.B. Tao, D. Massoubre, E.Y. Xie, X.D. Hu, Z.Z. Chen, G.Y. Zhang, Y.B. Pan, M.S. Hao, I.M. Watson, E. Gu and M.D. Dawson,**

'Electrical, spectral and optical performance of yellow-green and amber micro-pixelated InGaN light-emitting diodes', *Semicond. Sci. Technol.* **27**, 015003 (2012)

(BIO)MATERIAL SCIENCE

Effects of electric field-induced versus conventional heating

The effect of microwave heating and cell phone radiation on sample material is no different than a temperature increase, according to the present work.

Richert and coworkers attempted for the first time to systematically quantify the difference between microwave-induced heating and conventional heating using a hotplate or an oil-bath, with thin liquid glycerol samples. The authors measured molecular mobility and reactivity changes induced by electric fields in these samples, which can be gauged by what is known as configurational temperature. They realised that thin samples exposed to low-frequency electric field heating can have a considerably higher mobility and reactivity than samples exposed to standard heating, even if they are exactly at the same temperature. They also found that at frequencies exceeding several megahertz and for samples thicker than one millimetre, the type of heating does not have a significant impact on the level of molecular mobility and reactivity, which is mainly dependent on the sample temperature. Actually, the configurational temperatures are only marginally higher than the real measurable one.



▲ Study of mobile phone electric field shows no extraordinary heating

Previous studies were mostly fundamental in nature and did not establish a connection between microwaves and mobile phone heating effects. These findings imply that for heating with microwave or cell phone radiation operating in the gigahertz frequency range, no other effect than a temperature increase should be expected. Since the results are based on averaged temperatures, future work will be required to quantify local overheating, which can, for example, occur in biological tissue subjected to a microwave field, and better assess the risks linked to using both microwaves and mobile phones.

■ **A. Khalife, U. Pathak and R. Richert,**

'Heating liquid dielectrics by time dependent fields', *Eur. Phys. J. B* **83**, 429 (2011)

MATERIAL SCIENCE

Ordered Si oxide nanodots at atmospheric pressure

It is now possible to simultaneously create highly reproducible three-dimensional silicon oxide nanodots on micrometric scale silicon films in only a few seconds. The present study shows that one can create a square array of such nanodots, using regularly spaced nanoindents on the deposition layer, that could ultimately find applications as biosensors for genomics or bio-diagnostics.

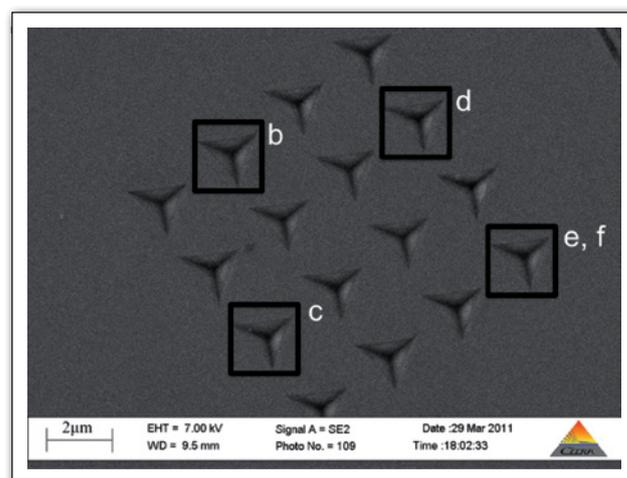
A process called atmospheric pressure plasma-enhanced chemical vapour deposition is used. This approach is a much faster alternative to methods such as nanoscale lithography, which only permits the deposition of one nanodot at a time. It also allows the growth of a well-ordered array of nanodots, which is not the case of many growth processes. In addition, it can be carried out at atmospheric pressure, which decreases its costs compared to low-pressure deposition processes.

One goal was to understand the self-organization mechanisms

leading to a preferential deposition of the nanodots in the indents. By varying the indents' interspacing, they made it comparable to the average distance travelled by the silicon oxide particles of the deposited material. Thus, by adapting both the indents' spacing and the silicon substrate temperature, they observed optimum self-ordering inside the indents using atomic force microscopy. The next step will be to investigate how such nanoarrays could be used as nanosensors. It is planned to develop similar square arrays on metallic substrates in order to better control the driving forces producing the highly ordered self-organisation of nanodots. Further research will be needed to give sensing ability to individual nanodots by associating them with probe molecules designed to recognise target molecules to be detected.

■ **X. Landreau, B. Lanfant, T. Merle, E. Laborde, C. Dublanche-Tixier and P. Tristant,**

'Ordering of $\text{SiO}_x\text{H}_y\text{C}_z$ islands deposited by atmospheric pressure microwave plasma torch on Si(100) substrates patterned by nanoindentation', *Eur. Phys. J. D* **65/3**, 421 (2011)



▲ SEM image of the surface morphology of $\text{SiO}_x\text{H}_y\text{C}_z$ nano-islands localized at the center of nano-indents

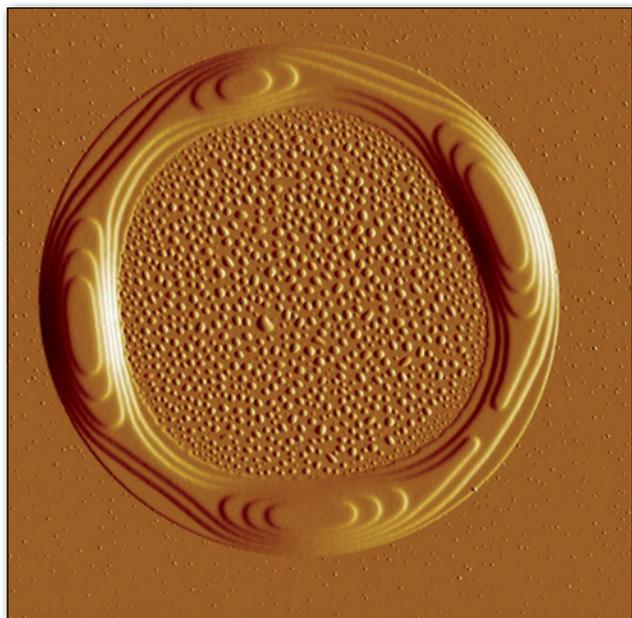
LIQUID PHYSICS

How to build doughnuts with Lego blocks

The present work reveals how nature minimises energy costs in rings of liquids with an internal nanostructure made of two chemically discordant polymers joined with strong bonds, or di-blocks, deposited on a silicon surface.

The authors first created rings of di-block polymers that they liken to building doughnuts from Lego blocks due to the nature of the material used, which has an internal structure discretised like Lego blocks, resulting in rings approximating the seamless shape of a doughnut (see photo).

The dynamics of interacting edges in ring structures that display asymmetric steps, *i.e.*, different spacing inside and outside



▲ A mix of two chemically discordant polymers with strong bonds creates previously unseen nanoscale assemblies.

the ring, when initially created, has been measured. It is found that the interaction shaping the ring over time is the repulsion between edges. The source of this repulsion is intuitive: an edge is a defect which perturbs the surface profile with an associated cost to the surface energy.

These edges could be considered as defects in a material with an otherwise perfect order at the nanoscale. Thus, research based on the elucidation of defect interactions could help scientists trying to eliminate such defects by understanding how these materials self-assemble. Such systems could also provide an ideal basis for creating patterns on the nanoscale, data storage, and nanoelectronics.

■ **J.D. McGraw, I.D.W. Rowe, M.W. Matsen and K. Dalnoki-Veress,**

'Dynamics of interacting edge defects in copolymer lamellae', *Eur. Phys. J. E* **34**, 131 (2011)

MATERIAL SCIENCE

How Ni-Ti nanoparticles go back to their memorised shape

Metallic alloys can be stretched or compressed in such a way that they stay deformed once the strain on the material has been released. Only shape memory alloys, however, can return to their original shape after being heated above a specific temperature.

For the first time, the authors determine the absolute values of temperatures at which shape memory nanospheres start changing back to their memorised shape – undergoing so-called structural phase transition, which depends on the size

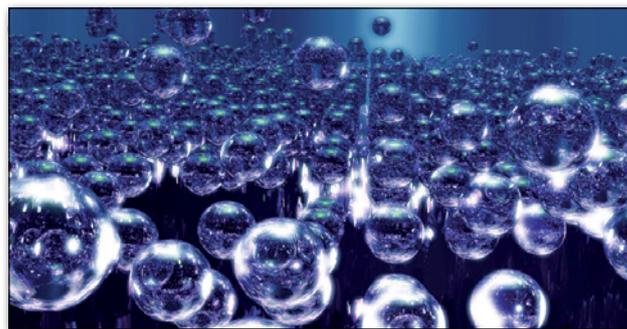
of the particles. To achieve this result, they performed a computer simulation using nanoparticles with diameters between 4 and 17 nm made of an alloy of equal proportions of nickel and titanium.

Using a computerised method known as molecular dynamics simulation, it is possible to visualise the transformation process of the material during the transition. As the temperature increases, it is shown that the material's atomic-scale crystal structure shifts from a lower to a higher level of symmetry. The strong influence of the energy difference between the low- and high-symmetry structure at the surface of the nanoparticle, which differs from that in its interior, explains the transition.

Most of the prior work on shape memory materials was in macroscopic scale systems. Potential new applications include the creation of nanoswitches, where laser irradiation could heat up such shape memory material, triggering a change in its length that would, in turn, function as a switch.

■ **D. Mutter and P. Nielaba,**

'Simulation of the thermally induced austenitic phase transition in NiTi nanoparticles', *Eur. Phys. J. B* **84**, 109 (2011)



▲ Can metals remember their shape at nanoscale, too?

QUANTUM PHYSICS

First quantum machine to produce four clones

This article presents a theory for a quantum cloning machine able to produce several copies of the state of a particle at atomic or sub-atomic scale, or quantum state. It could have implications for quantum information processing methods used, for example, in message encryption systems.

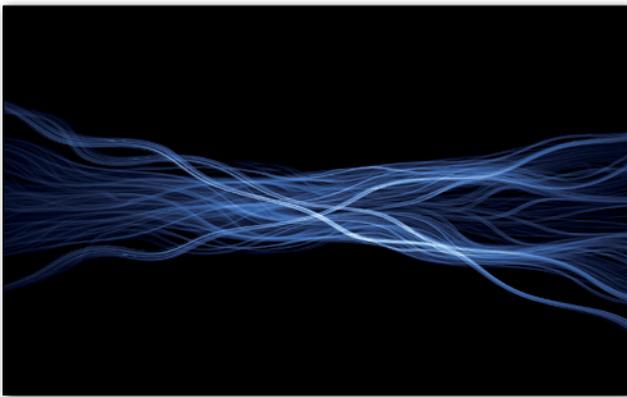
Quantum cloning is difficult because quantum mechanics laws only allow for an approximate copy—not an exact copy—of an original quantum state to be made, as measuring such a state prior to its cloning would alter it. The present work shows that it is theoretically possible to create four approximate copies of an initial quantum state, in a process called asymmetric cloning. The authors have extended previous work that was limited to quantum cloning providing only two or three copies of

the original state. One key challenge was that the quality of the approximate copy decreases as the number of copies increases. It appears possible to optimise the quality of the cloned copies, thus yielding four good approximations of the initial quantum state. The present quantum cloning machine is shown to have the advantage of being universal and therefore able to work with any quantum state, ranging from a photon to an atom.

Asymmetric quantum cloning has applications in analysing the security of messages encryption systems, based on shared secret quantum keys. Two people will know whether their communication is secure by analysing the quality of each copy of their secret key. Any third party trying to gain knowledge of that key would be detected as measuring it would disturb the state of that key.

■ **X.J. Ren, Y. Xiang and H. Fan,**

'Optimal asymmetric $1 \rightarrow 4$ quantum cloning in arbitrary dimension', *Eur. Phys. J. D* **65**, 621 (2011).



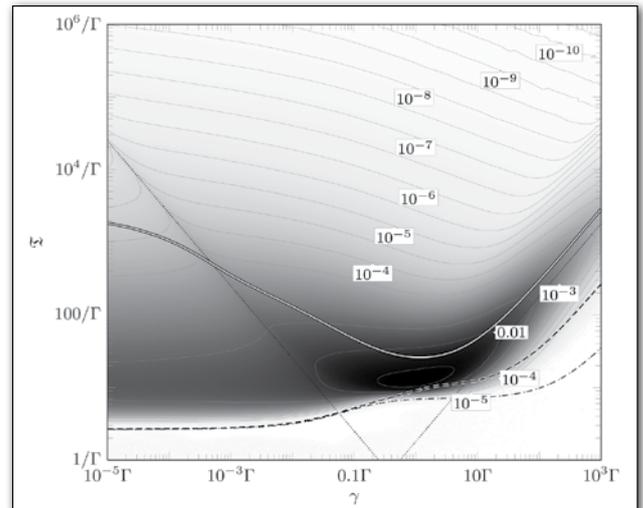
▲ These intertwined rays of light are an artistic metaphor for quantum cloning

QUANTUM (BIO)PHYSICS

Energy transport for biomolecular networks

Recent experimental demonstrations of long-lived quantum coherence in certain photosynthetic light-harvesting structures have launched a flurry of controversy over the role of coherence in biological function. An ongoing investigation into the astonishingly high-energy transport efficiency of these structures suggests that nature takes advantage of quantum coherent dynamics.

We inquire on the fundamental principles of quantum coherent energy transport in ensembles of spatially disordered molecular networks subjected to de-phasing noise. De-phasing reduces the coherence between individual network nodes and has already been shown to assist transport substantially provided that quantum coherence is disadvantageous by reason of destructive interference, *e.g.* in the



▲ Probability density of the average energy transfer time τ as a function of the de-phasing rate γ . As indicated by the median (white line), for a typical configuration, τ is reduced by the de-phasing up to an optimal rate γ , where the transfer becomes most efficient. However, these noise-assisted transfer times are longer than the minimum transfer time achieved by an optimized configuration for vanishing de-phasing (minimum of dot-dashed line on the left).

presence of disorder and quantum localization. In a statistical survey, we map the probability landscape of transport efficiency for the whole ensemble of disordered networks, in search of specially adapted molecular conformations that nature may select in order to facilitate energy transport: We thus find certain optimal molecular configurations that by virtue of constructive quantum interference yield the highest transport efficiencies in the absence of dephasing noise. Moreover, the transport efficiencies realized by these optimal configurations are systematically higher than the noise-assisted efficiencies mentioned above. As discussed in the article, this defines a clear incentive to select configurations for which quantum coherence can be harnessed.

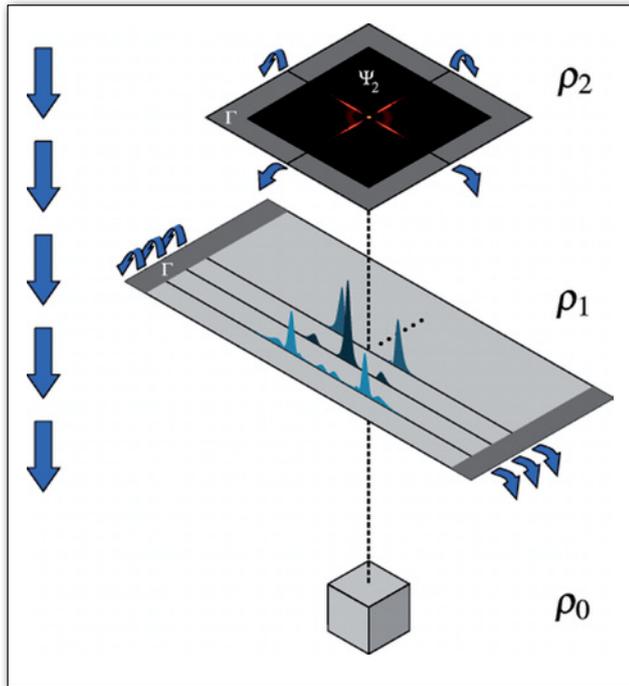
■ **T. Scholak, T. Wellens and A. Buchleitner,**

'The optimization topography of exciton transport', *EPL* **96**, 10001 (2011)

ATOMIC AND MOLECULAR PHYSICS

Double ionization with absorbers

In quantum dynamics, unbound systems, such as atoms being ionised, are typically very costly to describe numerically as their extension is not limited. This problem should be reduced if one could settle for a description of the remainder of the system and disregard the escaping particles. Removing the escaping particles may be achieved by introducing absorbers close to the boundary of the numerical grid. The problem is, however, that when such "interactions" are combined with the Schrödinger equation, all information about the system is lost as a particle



▲ The system is initially described by a two-particle wave function (top). As a particle is ionized and subsequently hits the absorber (Γ), the remaining electron is described by a one-particle density matrix (middle), which may be thought of as an ensemble of several one-particle wave functions. As also the one-particle system may be absorbed, the vacuum state may also be populated (bottom).

is absorbed. Thus, if we wish to still describe the remaining particles, a generalization of the formalism is called for. As it turns out, this generalisation is provided by the Lindblad equation. This generalised formalism has been applied to calculate two-photon double ionisation probabilities for a model helium atom exposed to laser fields. In the simulations, the remaining electron was reconstructed as the first electron was absorbed. Since there was a finite probability for also the second electron to hit the absorber at some point, the system could, with a certain probability, end up in the vacuum state, *i.e.* the state with no particles. As this probability was seen to converge, it was interpreted as the probability of double ionisation. The validity of this approach was verified by comparing its predictions with those of a more conventional method applying a large numerical grid.

■ S. Selstø, T. Birkeland, S. Kvaal, R. Nepstad and M. Førre,

'A master equation approach to double ionization of helium', *J. Phys. B: At. Mol. Opt. Phys.* **44**, 215003 (2011)

QUANTUM PHYSICS

Entanglement or separability

The present theoretical description of teleportation phenomena in sub-atomic scale physical systems proves that mathematical tools let free to choose how to separate out the constituting matter of

a complex physical system by selectively analysing its so-called quantum state. That is the state in which the system is found when performing measurement, being either entangled or not.

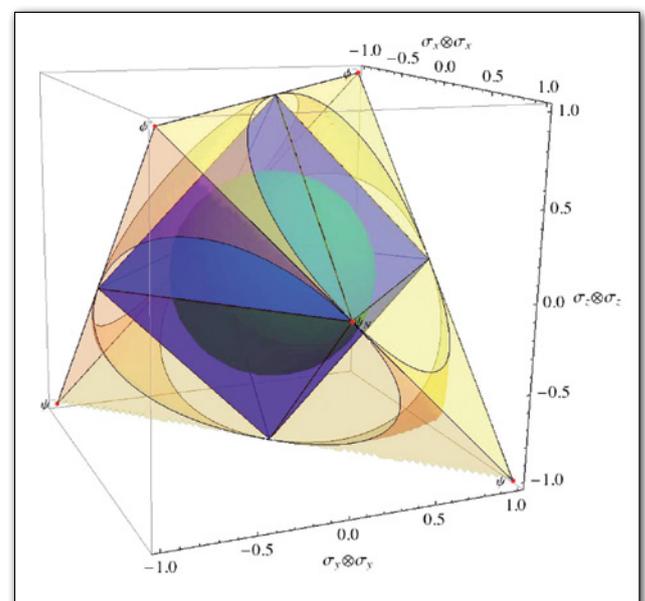
The state of entanglement corresponds to a complex physical system in a definite (pure) state, while its parts taken individually are not. This concept of entanglement used in quantum information theory applies when measurement in laboratory A (called Alice) depends on the definite measurement in laboratory B (called Bob), as both measurements are correlated. This phenomenon cannot be observed in larger-scale physical systems.

The findings show that the entanglement or separability of a quantum state – whether its sub-states are separable or not; *i.e.*, whether Alice and Bob were able to find independent measurements – depends on the perspective used to assess its status. A so-called density matrix is used to mathematically describe a quantum state. To assess this state's status, the matrix can be factorised in different ways, similar to the many ways a cake can be cut. The Vienna physicists have shown that by choosing a particular factorisation, it may lead to entanglement or separability; this can, however, only be done theoretically, as experimentally the factorisation is fixed by experimental conditions. This is applied to model physical systems of quantum information including the theoretical study of teleportation, which is the transportation of a single quantum state. Other practical applications include gaining a better understanding of K-meson creation and decay in particle physics, and of the quantum Hall effect, where electric conductivity takes quantified values.

■ W. Thirring, R.A. Bertlmann, P. Köhler and H. Narnhofer,

'Entanglement or separability: the choice of how to factorise the algebra of a density matrix', *Eur. Phys. J. D* **64/2**, 181 (2011)

▼ The separable quantum states form the blue double pyramid while the entangled states are located in the remaining tetrahedron cones



■ Herman C.W. Beijerinck - DOI: 10.1051/epn/2012101

■ Eindhoven University of Technology, the Netherlands - (H.C.W.Beijerinck@tue.nl)

A case of neglect...

Looking at the magazines of member societies of EPS and at Europhysics News, we have to conclude that they all have suffered a stroke. The 10% of the physics community that is university-employed and thrives on pure research is well served. Most of the content is geared to serve this minority. The other 90%, earning their daily wages in the 'real world', is neglected.

In medicine, 'neglect' is a well-defined term relating to cerebral damage due to an infarct. A patient with left-handed neglect will only eat what is served on the right-hand side of his plate. The damage does not heal. Is this the case for the physical societies? Or is there hope for healing?

Real-world careers

The majority of careers for physicists are not in academia, but elsewhere. Think of industry, consultancy, teaching, option trading, policy-making, think tanks and all the other institutions that serve society and keep our economy going. Some of these physicists just stop reading the bulletins but hold on to their membership. This can be considered as charity of disgruntled professionals for the academic membership. However, most will discontinue their membership and switch to other magazines.

For students at the M.Sc. and PhD level this narrow outlook on their professional life is rather confusing. Much worse is that university students are discouraged to become a member at all: they are already lost before the inaugural ball!

Why is this happening? Is it due to partial blindness of our university professors, who forget to tell about the beautiful and interesting work that physicists do in their careers outside university? Is it just self-interest, to fill the PhD positions in their research groups? Have we

forgotten that a university should be the major supplier of well-trained talent to society? Top level research is an excellent training tool, but it comes second to the *real* output of academia: independent, out-of-the-box thinking, talented youngsters, well trained in abstract analysis and a scientific approach to solve new problems in real life.

Community building

Wouldn't it be wonderful to cater to *all* physicists with a news bulletin that reflects the broad background of typical careers? Wouldn't it be exciting to increase our membership five-fold when all the 'lost sheep' return to the fold, by a bulletin that revitalizes all of us, including academia? Think of the financial basis this would supply for EPS. Think of the impact this will have when talking to the EU.

As an example, look at the Dutch Physical Society (NNV). In 2008, the membership was 3500 including retired members. With a B.Sc. at age 22, a lifespan of 85 years - for a male with an academic degree - and an estimated output of 250 students graduating each year from a Dutch university,

one obtains the incredible number of $63 \times 250 = 15,750$ potential members. The numbers will not differ that much for other member societies of EPS. This implies that we can gain a factor of *FOUR* in membership if we really shift our focus from the



minority in academia to the majority elsewhere.

A huge challenge lies before us! Of course, we cannot change overnight. But we can shift the focus of Europhysics News into a direction that reflects the majority of our community. We *can* make a difference and start nurturing the interaction between academia and industry. Academia should realize its role is to serve and not to dominate. ■

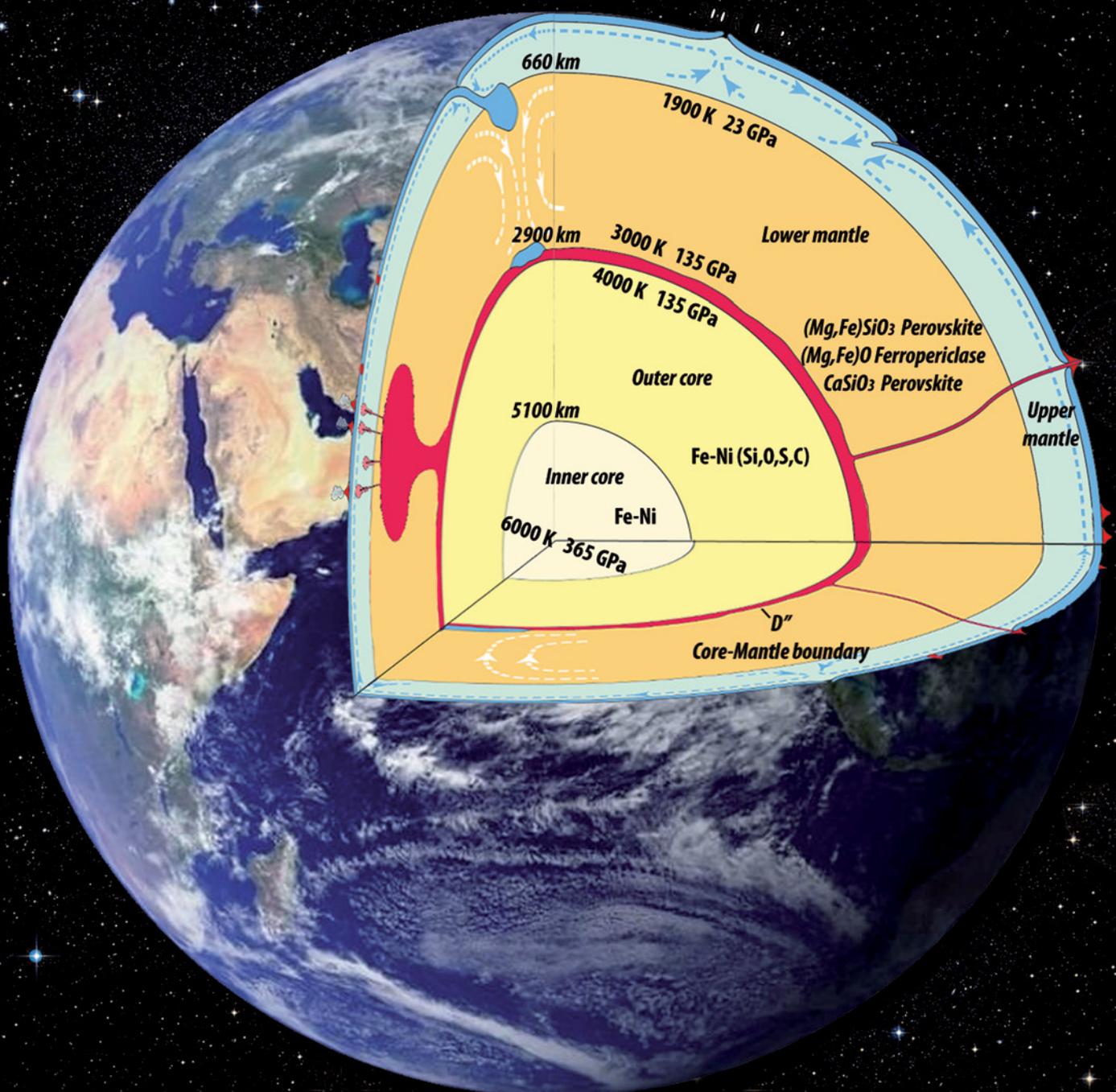
A new spin on

James Badro - Institut de Physique du Globe de Paris, France

DOI: 10.1051/epn/2012102

Earth's deep mantle

Earth's mantle is the largest distinct layer within the Earth, between the crust and the core. It accounts for roughly 2/3 of Earth's mass and is composed mainly of dense iron-bearing silicates. Laboratory experiments have recently shown that iron in mantle minerals undergoes a high-spin to low-spin transition driven by pressure, occurring at mid to lowermost mantle depths. This introduces a paradigm shift in our understanding of the physics and chemistry of the deep Earth.



Seismic wave analysis is the main tool for studying Earth's deep structure (figure 1). Radial seismological (1D) models, obtained from inversion of seismic travel times and normal mode spectra, give the compressional and shear wave velocities, as well as density, in the Earth as a function of depth. These profiles are characterised by smooth variations punctuated by sharp discontinuities. They reflect either chemical boundaries such as the core-mantle boundary at 2900 km depth, or physical boundaries such as the inner-core boundary at 5100 km.

Earth's mantle is composed mainly of silicates, and starts at 10 km below the oceanic crust and up to 70 km below the continental crust. It ends at the core-mantle boundary, at 2900 km depth. It is subdivided in Upper Mantle (shallower than 410 km), Transition Zone (410-660 km) and Lower Mantle (660-2900 km); the subdivision is derived from clear seismic discontinuities at the corresponding depths.

In one of their major achievements, high-pressure experiments have shown that the seismic discontinuities in the mantle are a direct consequence of phase transformations in mantle minerals and rocks. The behaviour and properties of terrestrial rocks and minerals can be studied at high pressure and high temperature, using presses such as the piston-cylinder press, the belt and toroidal presses, the multi-anvil press, or the laser-heated diamond anvil cell (LH-DAC) depicted in figure 2. The LH-DAC allows covering the entire pressure and temperature range in Earth's mantle, and a significant portion of that in the core. LH-DAC labs around the world can nowadays routinely achieve pressures in excess of 135 GPa (pressure at Earth's core-mantle boundary), while simultaneously heating the samples above 3000 °C using infrared lasers.

Composition

Although the question of a difference in bulk chemical composition between the upper and lower mantle is still a matter of debate, the mineralogy of these two reservoirs is, at any rate, fundamentally different. The upper mantle (and transition zone) is mainly composed of four-fold-coordinated silicate framework minerals (olivine, pyroxenes, garnets, and their high-pressure structural modifications), whereas the bulk of the lower mantle consists mainly of six-fold coordinated silicates – magnesium silicate perovskite (pv), $(Mg,Fe)SiO_3$, and calcium silicate perovskite ($Ca-pv$), $CaSiO_3$ – and a dense oxide ferropericlase (fp), $(Mg,Fe)O$.

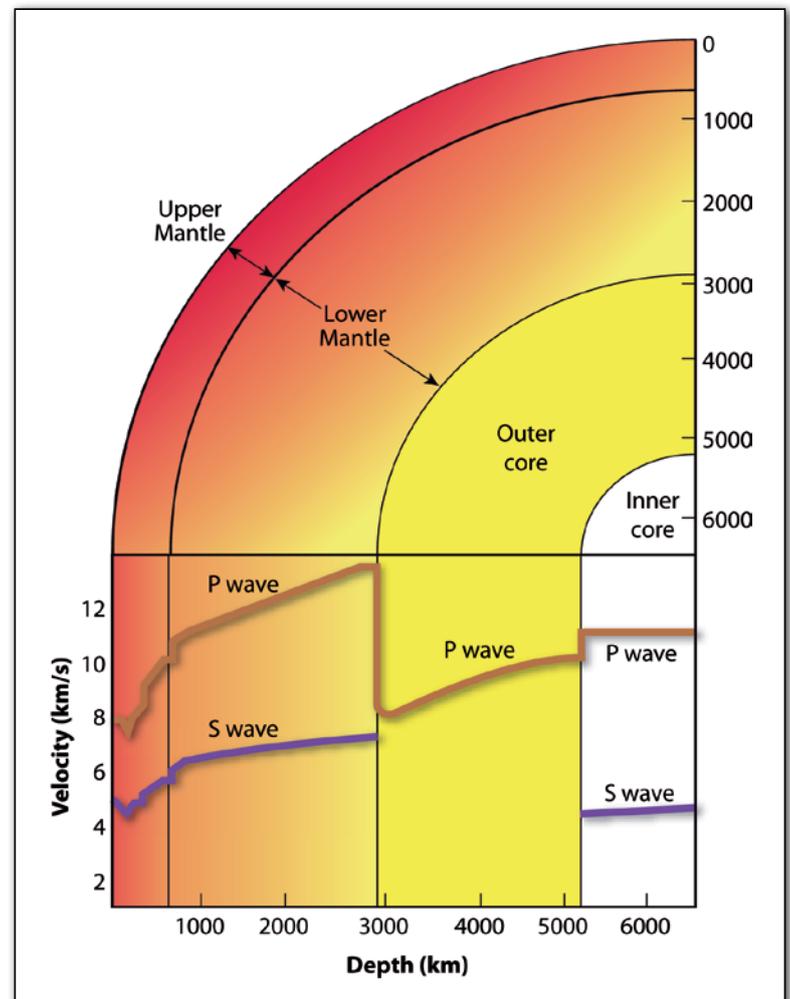
Iron-bearing minerals have complex physical and chemical properties, in contrast to the iron-free end-members. This is due to the electronic complexity of iron. The specificity of iron derives from the fact that it is a transition metal. Unlike the other major elements (Mg, Ca, Si, Al) of the bulk Earth, it has partially filled $3d$ orbitals that give rise to a series of possible electronic configurations

that depend on its atomic environment [1]. As a consequence, iron in mantle minerals adopts different valences such as ferrous (Fe^{2+}) and ferric (Fe^{3+}) iron, and different electronic configurations such as high-spin (HS) and low-spin (LS) iron.

Spin pairing

Half a century ago, William Fyfe [2] argued that elevated pressure could induce spin pairing in nominally HS minerals, and there was a possibility that this could occur in the pressure range of Earth's mantle, although the exact structure of the phases was still unknown. This is due to the fact that the spin state is determined by the balance between two energies: the crystal field stabilisation energy (favours the LS state) that increases with pressure, and the pairing energy (favours the HS state) that is essentially unaffected by pressure [3]. Thus, an iron-bearing mineral consisting of HS iron in the shallow mantle can undergo a pressure-driven transition to an LS state in the deeper mantle.

▼ FIG 1: (a) Schematic representation of the layers inside Earth: the names of the layers, their pressure, temperature, depth, and their composition. (b): The seismic wave velocity profiles (compressional and shear waves) as a function of depth. Except for the 2900-km boundary (the core-mantle boundary) which is compositional, the discontinuities have all been linked to phase transitions in the mantle or the core.



The fundamental differences in the physical and chemical properties of HS and LS iron can then play a crucial role inside the Earth, and affect the thermochemistry, elasticity, and dynamics of the entire planet; the hunting season for spin transitions in mantle minerals was open! It wasn't until recently that the breakthroughs in x-ray spectroscopy instruments on 3rd generation synchrotron sources combined with the enhanced LH-DAC technology allowed the direct probing of the spin state of geophysically relevant minerals at high pressure.



This introduces a paradigm shift in our understanding of the physics and chemistry of the deep Earth

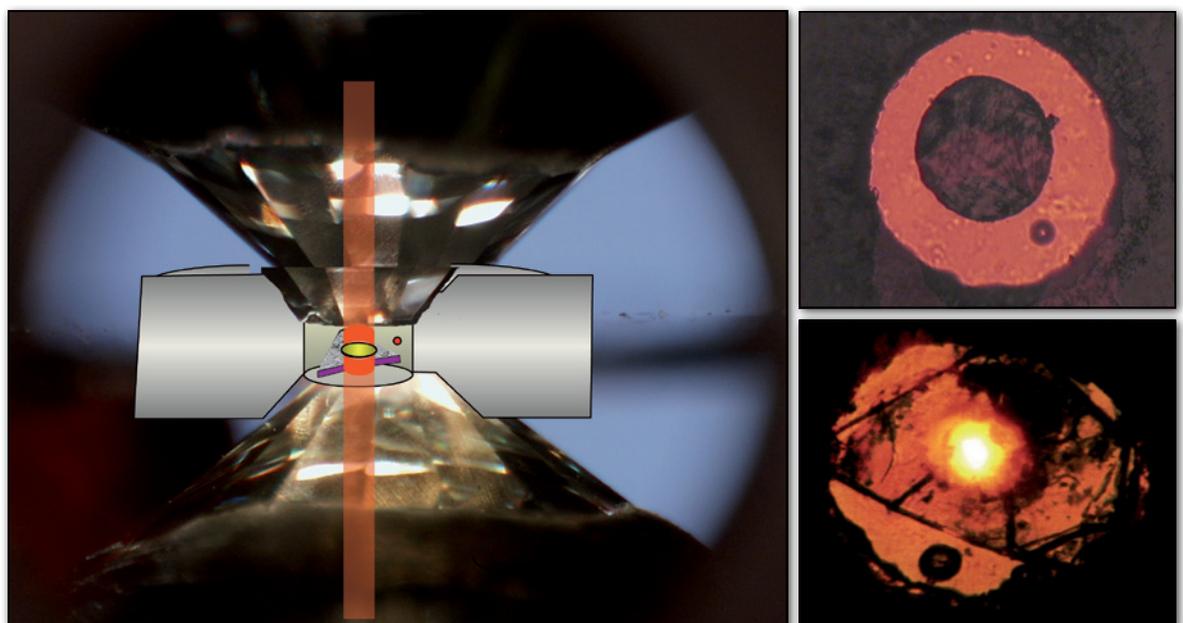
Using high-resolution x-ray emission spectroscopy, one can measure iron $K\beta$ emission and resolve the $K\beta'$ line from the main $K\beta_{1,3}$ emission line. The intensity of the $K\beta'$ line is linked to the spin magnetic moment of the Fe atom. In order to investigate the possibility of spin pairing at depth in the mantle, lower-mantle minerals $(Mg_{0.83}Fe_{0.17})O_{fp}$ and $(Mg_{0.9}Fe_{0.1})SiO_3_{pv}$ were pressurised in a LH-DAC [4,5], to pressures of 145 GPa (above mantle's maximum pressure of 135 GPa). A series of experiments were conducted in 2003 and 2004 at the ID16 inelastic scattering beamline of the European Synchrotron Radiation Facility, where a high-brightness 10 keV synchrotron x-ray beam was focussed onto the sample through the diamond anvils. The spin magnetic moment of iron in both minerals was measured as a function of pressure by monitoring the intensity of the $K\beta'$ line (figure 3). For the first time since Fyfe's

conjecture, spin pairing was observed in lower-mantle minerals at high pressure. The measurements show that iron in fp undergoes a change from HS to LS between 50 and 70 GPa at room pressure. It was later shown that increasing temperature increases the transition pressure (90 GPa at mantle temperatures) and broadens the HS-LS coexistence domain. In pv , a sharp transition to a full LS state is observed at 120 GPa (figure 3). Mantle minerals in the bottom 300 km (120 GPa) are entirely low-spin.

Geophysical differences

Geophysical interest in these transitions could seem odd, but is highly justified: spin pairing has a radical effect on important physical parameters, and on the lower mantle as a whole. LS minerals have a smaller molar volume (because LS Fe is smaller than HS Fe) and therefore a higher density than their HS counterpart, as well as a higher bulk modulus. Very accurate [6] x-ray diffraction experiments on fp around the spin transition pressure have confirmed the density effect: a subtle yet distinguishable kink in the equation of state $V(P,T)$ of fp is observed, as one crosses the spin transition, and the LS fp lies on a denser isotherm than the HS phase. The adiabatic bulk modulus also changes and increases, but in such a way that the seismic parameter K_S/ρ (where K_S is the adiabatic bulk modulus and ρ is the density) is unchanged. This has been proven recently [7] by inelastic x-ray scattering experiments, where density variations are observed, but wave speeds are not affected. Wave speeds are one of the seismological observables in the Earth, and it is remarkable that no change in the radially averaged 1D seismic parameter is observed. From

▼ FIG 2: Schematic representation of the laser-heated diamond anvil cell. The sample is compressed in a small metallic chamber in between two opposed diamond anvils. Pressures well above a megabar (100 GPa) can be routinely reached. By focusing infrared lasers on the sample through the anvils, we can simultaneously heat under pressure, to temperatures above 3000 K. Upper right: a sample (disk) seen through the diamond anvils, along the compression axis. The small ball is made of ruby and is used as a pressure gauge. The transparent medium surrounding the sample is usually a noble gas or an alkali halide. Lower right: a quartz sample heated by an infrared laser. The temperature at the center of the spot can routinely reach 3000 °C.



an observational point of view, and as opposed to the crystallographic transitions in the mantle that have their associated seismic discontinuities, these (spin-pairing) transitions are seismically transparent.

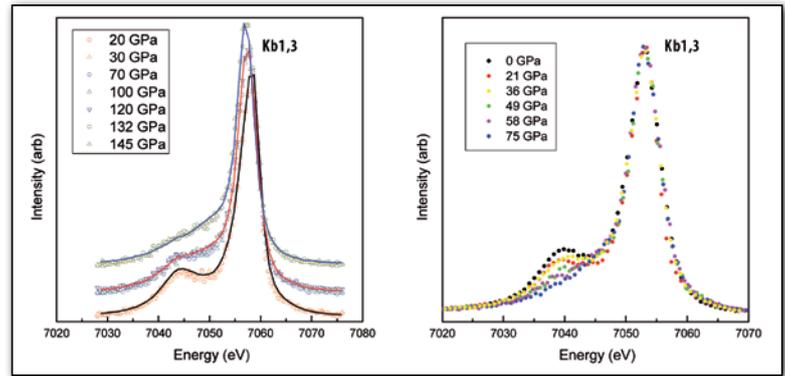
The thermodynamics and phase equilibrium between minerals can be affected by spin transitions (bear in mind that the $P\Delta V$ term in Gibbs free energy is order of magnitudes larger at mantle pressures than at ambient). Iron in the mantle is distributed in a solid solution by substitution with magnesium, in fp (Mg,Fe)O and pv (Mg,Fe)SiO₃. The relative concentration of iron in the two phases, or partition coefficient, is constrained by the minimisation of the Gibbs free energy for the substitution (or exchange) reaction: $Mg^{fp} + Fe^{pv} \rightleftharpoons Mg^{pv} + Fe^{fp}$. The fact that the LS iron atom has a smaller volume than its HS counterpart will favour the enrichment of Fe in the LS phase over to the HS phase. Although the rocks' bulk chemistry is constant, the distribution of elements in the minerals that make up the rock is changing. The rheological and physical properties of the rocks become very different. Since pv is likely the interconnected phase, its depletion in iron should increase its viscosity and stiffen the mantle at large depth. An important effect on the dynamics in the mid-mantle (1800 km) has been suggested, where the transition has been proposed to enhance plume (hot rising material) upwelling [8], by adding a spin-related buoyancy to hot upwelling material in the mid-mantle.

Heat transport

Dynamical simulations have suggested that a fully LS low-ermost (2600-2900 km) mantle would stabilise large thermal structures (super-plumes) while trimming small-scale structures [9]. Indeed, heat can be transported in the mantle by conduction, radiation, or convection. Convection in the lower mantle is only initiated if the other two processes fail to transfer heat, *e.g.*, if the ratio between heat transport through convection and heat transport through conduction and radiation is high enough. Changes in the conduction or radiation properties of lower-mantle mineral assemblages will therefore strongly affect lower-mantle dynamics. One of the main and intrinsic characteristics of LS iron-bearing minerals resides in the blue-shift of iron absorption bands (the absorption bands initially in the infrared shift to the visible). This would increase the radiative thermal conductivity of the minerals [10,11]. A mantle with a thermal conductivity jump (due to spin pairing) can stabilise a thermal boundary layer atop the core-mantle boundary [12], in which large upwellings are favoured, and could be the birthplace of super-plumes.

Important consequences

As we see, a small unexpected effect (spin pairing in mantle minerals) can have important consequences on the dynamics of the Earth as a whole, and as was mentioned by Fyfe [2] in 1960, and subsequently relayed by Burns and Sherman [1,3]:



▲ FIG 3: X-ray K β emission spectra of iron in the lower mantle's principal minerals: Mg-perovskite (pv , left) and ferropericlase (fp , right), at various pressures. The intensity of the K β ' peak, characteristic of the spin quantum state, vanishes at high pressure, indicative of a pressure-driven spin-pairing transition (the spectra have been shifted vertically for pv for clarity). The high-spin (HS) and low-spin (LS) states coexist over a rather large pressure interval (tens of GPa), and the conversion to the LS state is complete at 60-70 GPa for fp and 120 GPa for pv . In the latter case, this corresponds to 300 km above the core mantle boundary. According to those findings, the base of the mantle should be entirely made of LS iron.

The effect of pressure deep inside Earth's mantle may be to collapse the atomic orbitals of iron from the high-spin to the low-spin state. The transition represents a major change in the chemical bonding character of one of Earth's most important elements. Density, elastic moduli, thermal conductivity, electrical transport, and other physical and chemical properties of Fe-bearing minerals could thus be dramatically altered at depth.

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The Rediscovery of the 'French Blue' diamond

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Jean-Baptiste Tavernier (1605-1689), a French traveler, returned from India in 1668, with a large (115.16 carats) blue diamond from an unknown mine in India [1,2]. After the King of France, Louis XIV (1638-1715), purchased the gem, it became the largest diamond of the French Crown Jewels. Alas, in September 1792, this very unique and large blue diamond was stolen along with other gems of the French Crown Jewels [2]. Although most were eventually recovered, the ‘French Blue’ diamond never reappeared [1-3].

However, in 1812 a deep blue diamond of 45.5 carats was held in London by Daniel Eliason, a British diamond merchant [3]. Suspicions arose that this stone was illegally cut from the stolen ‘French Blue’ [4], losing about 1/3 of its weight as well as its 17th century cut [2-4]. But no proof could be found, for lack of accurate information about the ‘French Blue’ before its robbery. This gem, called the ‘Hope diamond’ after its first owner, went through a succession of owners until it was donated in 1958 by Harry Winston to the Smithsonian Institution in Washington, D.C., (USA) [3]. Despite the fact that the ‘Hope diamond’ was believed to represent the modern avatar of the stolen ‘French Blue’, no thorough proof was available to verify this hypothesis.

Historical lead model

A recent inventory of the mineral and gem collection of the *Muséum national d’Histoire naturelle* in Paris revealed the presence of a previously unknown unique lead cast of the ‘French Blue’ diamond, donated sometimes between 1800 and 1850 [1]. To study this old and fragile cast, the artefact was laser-scanned [1] in order to obtain a 3D mesh of the diamond (Figure 1). The surface scanning was so sensitive that it revealed more than 3000 individual surfaces, while the actual number of ‘true facets’ was estimated by eye to be around 78. In this study, we present a more reliable ‘mesh cleaning’, achieved using a quadratic collapse edge decimation method (Meshlab package).

True color of the ‘French Blue’

The cleaned mesh was compared in 3D to a series of known blue diamonds that are claimed to be modern avatars of the ‘French Blue’, namely the ‘Hope’ (44,5 carats) and the ‘Terenschenko’ (40,5 carats) diamonds. However, only the ‘Hope’ diamond could fit into the scanned lead cast (Figure 1). In fact, the asymmetric shape of the ‘Hope’ diamond seems directly related to the triangular shape of the ‘French Blue’ [1].

On the other hand, the ‘Hope’ is described as a dark grayish blue diamond [5]. But was that the case for the ‘French Blue’ diamond? In fact, lapidarists know very well that a given cut can significantly alter the color of



a gem. Actually, when the ‘Hope’ diamond is held above a white paper, the diamond appears dark grayish blue, except at its center where it absorbs much less light. As a result, one can easily see the background paper through the gem (see Figure 1). This tells us that the ‘Hope’ diamond is, in fact, cut from a relatively light blue diamond. Its peculiar XIXth-century cut apparently makes it dark blue because the light is trapped inside the diamond by facets cut mostly at an angle greater than the critical angle of diamond (around 24.4° for the diamond/air boundary). This means that the large front facet (called the ‘table’) and the small facet cut in the back of the diamond (called the ‘cutlet’, parallel to the table) will behave as transparent boundaries for the viewer. In contrast, all the other facets will reflect light inside the diamond due to total internal reflection, because the angle between the incident light and the facet is usually above the critical angle of diamond. As a consequence, light absorption will be enhanced thanks to those facets, until light is eventually reflected back to the viewer. Hence, the apparent blue color of the diamond is rather intense (that is, dark) while the actual diamond color is light blue. Where does this color come from?

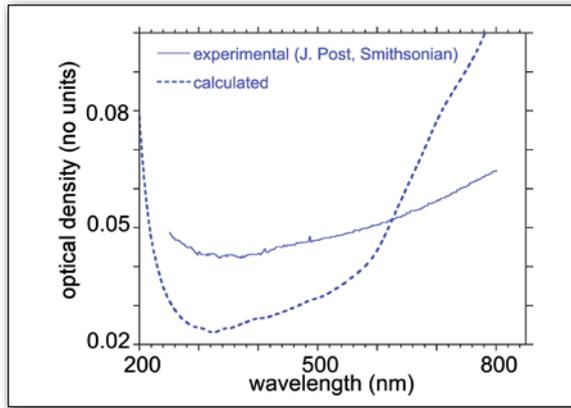
Blue diamonds

Only a modest number of blue diamonds are known nowadays, mostly from India (‘Wittelsbach’, ‘Terenschenko’, ‘Hope’) and South Africa (‘Copenhagen Blue’). The latter (45,9 carat) is the largest blue diamond presently known, although well below the past ‘Tavernier Blue’ (115.4 carat) and ‘French Blue’ (69.0 carat) diamonds, while a nameless diamond weighing 121.9 carat is reported to exist

▲ **FIG. 1:** The Paris lead cast (30.5 mm width) and the dismantled ‘Hope’ diamond (courtesy Smithsonian Institution, Washington, DC, USA).

◀ cubic zirconia replica of the ‘French Blue’ in the royal gardens of Versailles. Also shown is a lead cast, rediscovered in Paris in 2008, of the original diamond.

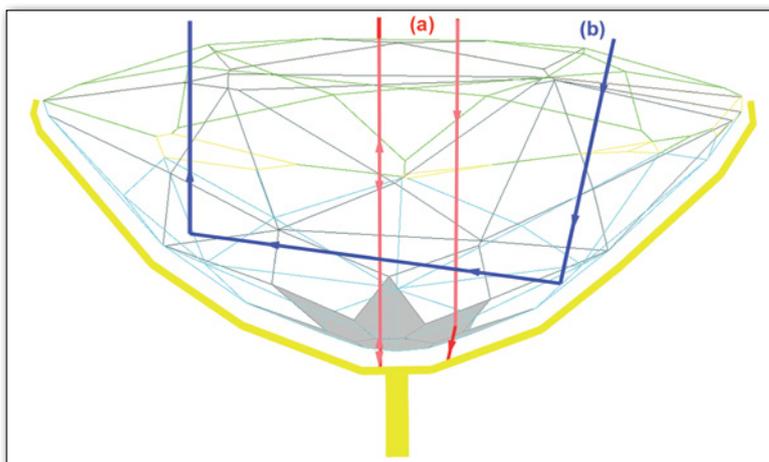
► **FIG. 2:** Optical spectroscopy spectrum measured for the ‘Hope’ diamond (courtesy of Smithsonian Institution, Washington, DC, USA) together with a computer spectrum assuming a boron atom inside a 63-carbon atom cluster.



[6]. Interestingly, type IIb blue diamonds are depleted of N_2 (i.e., below current detection levels [7]) but boron-bearing (a few ppm) [8]. In addition to having high thermal conductivity and dielectric strength, unlike other diamonds they are semiconductors to superconductors [9]. B-bearing diamonds have an acceptor state at 0.385 eV above the valence band. These features also make blue diamonds very much investigated for their impressive electrical properties [7,9], e.g., in high voltage diodes, transistors and electrochemical electrodes.

In diamond, the blue color typically arises from small amounts – on the order of ppm – of B atoms [5,10] (the color of some blue-green to violet diamonds from Argyle, Australia, is not related to B [8]). B and C are trivalent and tetravalent, respectively. So, when C is substituted by B, an electron vacancy is created: B can act as a semiconductor acceptor (p-type). This can be compensated by a single N substitution, which acts as an electron donor. Only ‘uncompensated’ B atoms (B_0) will contribute to the color [7,8,10]. Some blue diamonds exhibit strong chemical and color zoning, for example the ‘Hope’ diamond [10]. The B atoms strongly enhance optical absorption in the red part of the visible wavelengths up to the IR region

▼ **FIG. 3:** Sketch illustrating how light (blue and red paths) is refracted inside the ‘French Blue’ diamond when it was set into a gold stick (yellow). (a): Red light crosses through the boundary facets (in gray) that were cut with an angle ~ 0 and 20° , i.e., below the critical angle of diamond. (b): Blue light is refracted inside the diamond as the incident angle of that facet (in white) is above the critical angle of diamond.



($\sim 3.5 \mu\text{m}$). This gives a blue color to the transmitted light for those diamonds, but the intensity of the perceived color is not a straightforward function of the B_0 content [10]. Gem faceting strongly alters the perception of its intrinsic color, and the perceived color of a cut gem is typically estimated using empirical color gradings. Finally, some blue diamonds exhibit a grayish hue that is likely due to the presence of a brownish component related to distortion [5].

Despite the great complexity of our perception of color, the optical absorption spectroscopy of the ‘Hope’ diamond was measured using a high-resolution charge-coupled device (CCD) spectrometer (Ocean Optics HR2000) with a 5 nm slit width and a light source (Ocean Optics DH-2000) that was used with both the deuterium and halogen light sources, covering a wavelength range of 215–2000 nm (Figure 2). The spectrum was measured between 250 and 900 nanometers, which is enough to get good quantitative information on its intrinsic color, independent of its faceting. To understand and better model this property, theoretical first-principles Bethe-Salpeter Equation calculations [11] of the optical absorption of substitutionally B-doped diamond were carried out. We started from a supercell with 63 C atoms and one B atom in a DFT-relaxed diamond crystal structure using ABINIT [12,13]. Based on this cluster, an UV-VIS-NIR optical spectrum was calculated that is comparable to that measured for the ‘Hope’ diamond (Figure 2: details will be published later). Briefly, the results show that B-doped diamonds absorb preferentially in the red, and strongly above about 700 nm due to the presence of a B impurity band, consistent with their ‘cold blue’ color.

Virtual recreation

The experimental optical absorption spectrum for the ‘Hope’ diamond was also used to photorealistically simulate the ‘French Blue’ diamond, using the mesh described above as input to the DiamCalc software. Special care was given to parameterize the illumination conditions (color temperature etc). In addition, we set the diamond according to the 1691 inventory of the French Crown Jewels that states that the gem was “violet and set into gold and mounted on a stick” (probably designed to facilitate the observation of the gem by the king). Therefore, a gold foil was set behind the 3D mesh of the diamond. This detail is relevant because the ‘French Blue’ has 8 back facets that are cut below the critical angle of diamond. Thus, one expects that those 8 central facets will allow the observation of the back gold foil. On the other hand, the 70 other facets will contribute to darken the intrinsic colour of the natural diamond (see paths (a) and (b) in Figure 3). But the question remains: what was the exact color — blue or violet — and fieriness?



◀ **FIG. 4:** The final photorealistic simulation of the 'French Blue' diamond when set into gold, following the 1691 inventory of the French Crown Jewels.

An unsuspected masterpiece

A photorealistic simulation of the "French Blue" is shown on Figure 4. As predicted, we could observe that the 8 central facets that are 'golden'. The 70 other facets contribute to the dark blue hue of the diamond, but not as dark as the 'Hope'. This superb optical illusion is due to an excellent understanding of the critical angle of diamond that was obviously well known (most likely heuristically) by the King's jeweler, Jean Pittan the Younger (ca.1617-1676) [1]. Also, the 'French Blue' diamond is more indigo than the 'Hope': the adjective 'violet' referred to an intense blue during the 17th century [2]. Therefore, this diamond was cut to the colors of the French monarchy "*of azure and gold*": it served as a political instrument devoted to the power of the King. Accordingly, the central golden motif acts as a central sun, the favorite icon of King Louis XIV, also known as the "Sun-King".

To summarize, we needed to use modern computers and sophisticated software to recreate and understand the optical properties of a forgotten 17th century masterpiece that served the image and power of the King of France. A spectroscopic understanding of the exact color of the 'Hope' diamond has given us access to that lost *chef d'oeuvre*. ■

Acknowledgments

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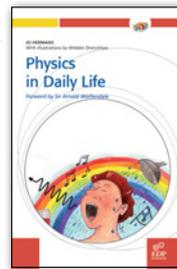


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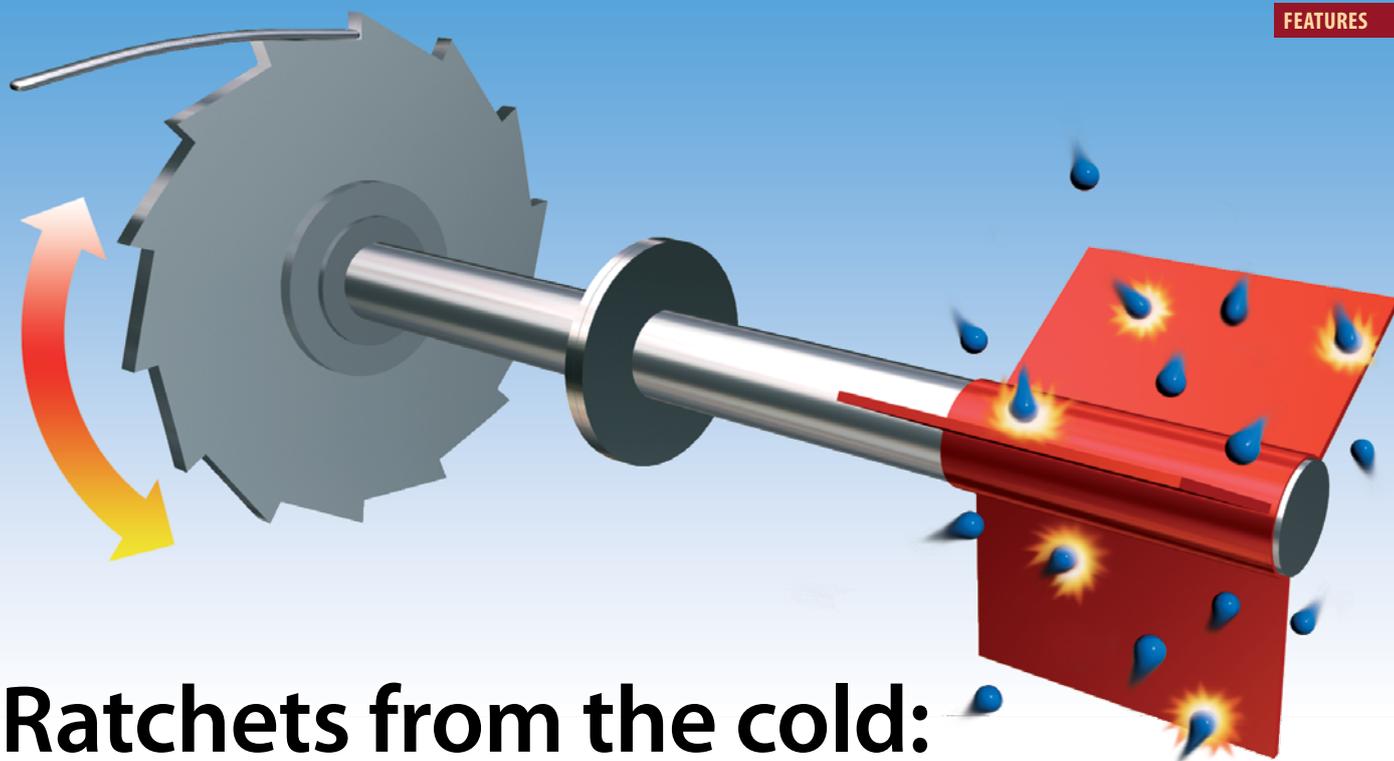
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THE 'PHYSICS IN DAILY LIFE' PAGE WIDENS ITS SCOPE

Many of you have appreciated the 'Physics in daily life' page for more than six years. In response to the suggestions of several readers, the 40 items which appeared thus far have been collected in a booklet (see elsewhere on this page).

We now wish to open the door to a column with a wider scope, covering opinions and – possibly controversial – letters from our readers. Our goal is to have such a column in each issue along with the traditional 'Physics in daily life' column,

hoping that our talented cartoonist will be inspired to produce an appropriate illustration each time. Her talents are exemplified also on this page (illustrations taken from the 'Physics in daily life' book).



Ratchets from the cold:

Brownian motors with cold atoms in optical lattices

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Brownian motors, or ratchets, are devices which ‘rectify’ Brownian motion, that is, they can generate a current of particles out of unbiased fluctuations. The present article reviews recent experimental realizations of ratchets employing cold atoms in optical lattices. This is quite an unusual system for a Brownian motor as there is not a real thermal bath, and both the periodic potential for the atoms and the fluctuations are determined by laser fields. Such a system has allowed us to explore a number of fundamental features of ratchets.

Brownian motors, or ratchets, are devices which “rectify” fluctuations, turning unbiased Brownian motion into directed diffusion, in the absence of any net applied bias forces [1]. These unusual devices have been attracting growing attention in different communities involving a number of applications: including, for example, particle separation, the modelling of molecular motors, and the realization of novel types of electron pumps, just to name a few.

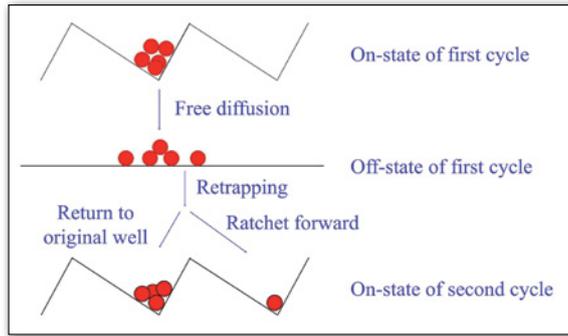
A Brownian motor generates a current from unbiased fluctuations. Strict limitations on the operation of a ratchet are imposed by the second law of thermodynamics, which rules out the possibility of producing a current at thermodynamic equilibrium [2]. Thus, the effective generation of a current requires the system to be driven away from equilibrium. How this can be implemented is best demonstrated by considering two specific examples of ratchet devices: the flashing and the rocking ratchets.

The flashing ratchet

Consider a sample of Brownian particles in a (static) asymmetric periodic potential. The second principle of thermodynamics rules out the possibility of directed motion. However, things are very different if the potential is “flashed”, *i.e.* if it is turned on and off repeatedly, either periodically or randomly [3]. This is sufficient to set the Brownian particles into directed motion, due to the mechanism illustrated in Fig. 1.

Consider an initial situation with the potential turned on and the Brownian particles localized at the bottom of a given well. Then the potential is turned off, and the Brownian particles will symmetrically diffuse in space. Then the potential is turned on again, and the Brownian particles are retrapped in both the original well and in a few neighbouring ones. However, as the potential is asymmetric the retrapping will lead to an asymmetric situation, with the number of particles trapped in the

▲ Artist impression of the ratchet.
© Antoine Tisserand



► FIG. 1: Working principle of the flashing ratchet

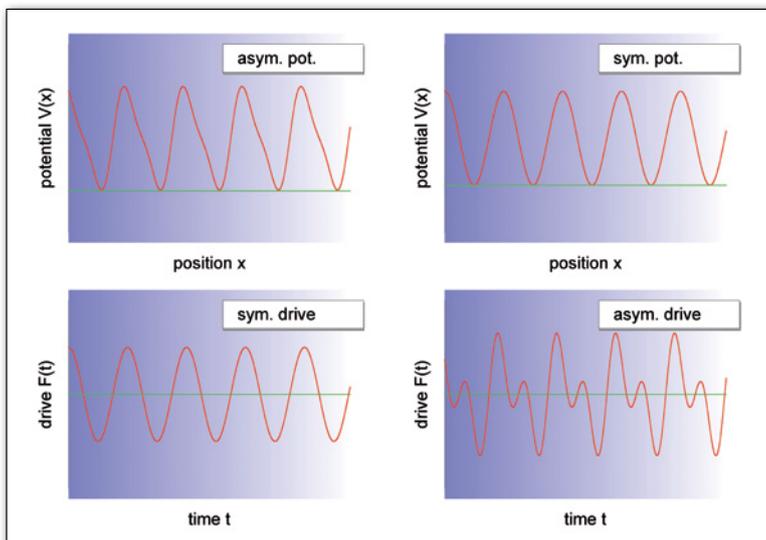
wells to the left of the original well different from the number of particles trapped in the wells to the right of the starting location. Indeed it is clear from Fig. 1 that the wells located at the right of the starting well will collect more particles during the retrapping phase. This because these wells are closer to the “steep wall” of the original well, therefore the atoms have to travel less to be retrapped there. In this way the centre of mass of the particle cloud will move, and directed motion is thus obtained.

It is important to point out why the operation of the flashing ratchet does not violate the second law of thermodynamics. This is because work is done on the system while turning on the potential. Thus, although fluctuations are rectified and a current is generated, this does not imply that work has been extracted out of just one heat source as some additional work was necessary to turn on the potential. Therefore the second law is not broken.

The rocking ratchet

In the *rocking* ratchet [4], particles in a periodic asymmetric potential also experience an applied ac (alternating) force. The applied force, which is zero-average and time-symmetric, drives the system out of equilibrium (see Fig. 2, left column). As a result of the asymmetry of the potential, a net current of particles can be generated.

▼ FIG. 2: Different choices of potential $V(x)$ and ac drive $F(t)$ for the realization of a rocking ratchet. In the left column, $V(x)$ is spatially asymmetric and $F(t)$ temporally symmetric. In the right column, $V(x)$ is spatially symmetric and $F(t)$ temporally asymmetric.



The same effect can be obtained for a spatially symmetric potential and a temporally asymmetric drive (see Fig. 2, right column). A bi-harmonic force is a popular choice for a time-asymmetric drive, with the time-symmetry of the drive controlled by the relative phase between harmonics (details in Box).

In general, the operation of a ratchet requires two main elements: an out-of-equilibrium set-up, so as to overcome the limitations imposed by the second law of thermodynamics, and the breaking of the symmetries which would otherwise prevent directed motion. Box 1 reviews the symmetry analysis for the specific case of ac driven ratchets [5].

Rocking ratchets for cold atoms

Optical lattices are periodic potentials for atoms created by the interference of two or more laser fields [6]. In dissipative optical lattices a set of laser fields – see Fig. 3 – produce at once the periodic potential acting on the atoms and a dissipative friction mechanism. In these lattices the depth of the optical potential can be varied at will by properly choosing the laser parameters. Likewise it is possible to vary the damping rate of the atomic velocity, by varying the scattering rate of the photons. The possibility of varying the damping rate is essential to investigate the phenomenon of dissipation-induced symmetry breaking which will be described in the following.

Dissipative optical lattices thus offer two essential elements for the realization of rocking ratchets: the periodic potential, and a fluctuating environment which results in a friction and in a fluctuating force. The last element necessary to implement a rocking ratchet is the oscillating force. This is easily achieved, as an arbitrary time-dependent homogeneous force can be generated by phase-modulating one of the lattice beams.

Experimental demonstration

The first rocking ratchet for cold atoms was experimentally demonstrated in 2003 [7], using a spatially *symmetric* optical lattice and a bi-harmonic drive. The dynamics of rubidium atoms in the optical lattice was studied by direct imaging of the atomic cloud with a CCD camera. It was found that the center of mass of the atomic cloud can be set into motion with constant velocity despite the fact that the oscillating force has zero average. Furthermore, the velocity showed the expected $\sin(\varphi)$ dependence on the phase φ consistent with the symmetry analysis for a dissipationless system (see Box 1). This because this experiment was performed in the regime of relatively strong driving and small damping, which approximates well the dissipationless regime.

A similar set-up to the one described above was used in a subsequent experiment [8] to provide the first

experimental evidence for dissipation-induced symmetry breaking in a rocking ratchet.

Different sets of measurements were performed for different values of the photon scattering rate, which characterizes quantitatively the level of dissipation in this system. The measured current of atoms (see Fig. 4) was found to be well approximated by $\sin(\varphi - \varphi_0)$. The measured phase shift φ_0 is zero, within the experimental error, for the smallest scattering rate examined in the experiment. In this case, no current is generated for $\varphi = n\pi$, with n integer, as for these values of the phase the system is invariant under time-reversal transformation. The magnitude of the phase shift φ_0 increases at increasing scattering rate, and differs significantly from zero. The nonzero phase shift corresponds to current generation for $\varphi = n\pi$, *i.e.* when the system Hamiltonian is invariant under the time-reversal transformation. This result demonstrates the predicted (Box) breaking of the system symmetry by dissipation.

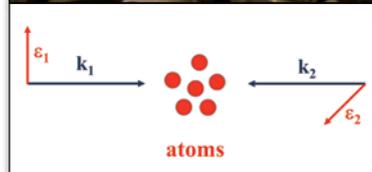
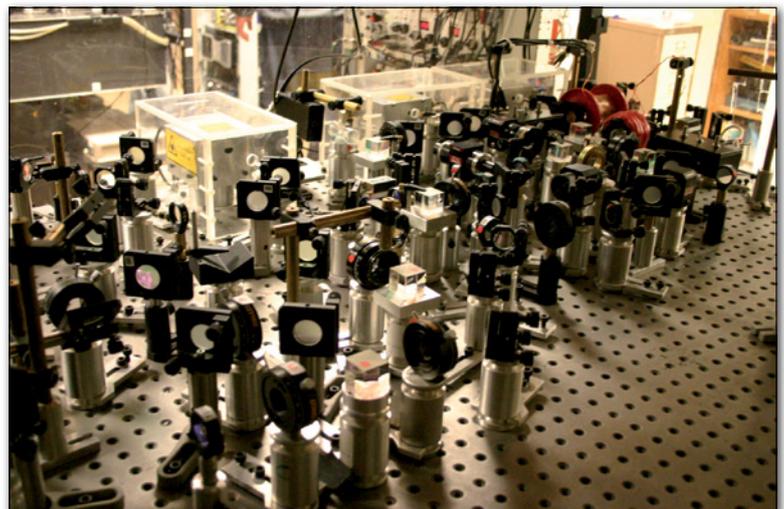
This demonstrated tunability of cold atom systems allows one to go beyond the basic ratchet corresponding to a bi-harmonic rocking force. Indeed, gating ratchets and quasiperiodically driven ratchets have also been demonstrated.

In the gating ratchet [9], particles experience an oscillating potential which is spatially symmetric. A zero-average and time-symmetric ac force is also applied. A current can be generated following a gating effect, with the lowering of the potential barriers synchronized with the motion produced by the additive force. This mechanism has to be contrasted with the previously discussed ac-driven ratchets with additive bi-harmonic driving, in which the underlying mechanism is harmonic mixing, where a nonlinear medium (the periodic potential) mixes the two harmonics producing a current. A gating ratchet for cold atoms was demonstrated experimentally by [10]. The ratchet was realized with cold atoms in a driven dissipative optical lattice. A single-harmonic periodic modulation of the potential depth was applied, together with a single harmonic rocking force. Whenever the relative phase between the modulation and the rocking force was such to break the relevant symmetries, directed motion was observed.

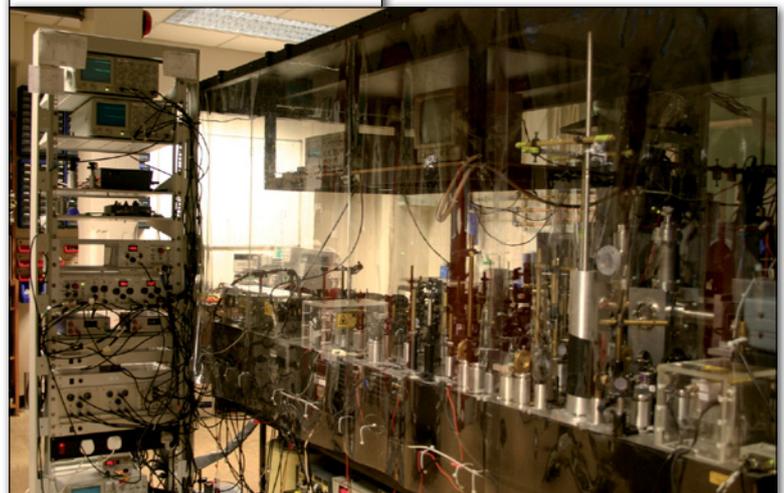
In the case of quasiperiodically driven ratchet [11], the interesting issue is how the symmetries, and the resulting current generation, are modified following the transition from periodicity to quasiperiodicity. Consider a generic driving force with two frequencies ω_1, ω_2 . Quasiperiodic driving corresponds to an irrational value of the ratio ω_1/ω_2 . It can be shown that in the case of a quasiperiodic driving, the two phases $\omega_1 t, \omega_2 t$ can be treated as *independent* variables. In other words, there is an effective change in the dimensionality of the system in the transition from periodicity to quasiperiodicity. The symmetry of the system, and the corresponding conditions to observe

a ratchet current, change accordingly. Clearly, in a real experiment ω_1/ω_2 is always a rational number, which can be written as $\omega_1/\omega_2 = p/q$, with p, q two coprime positive integers. However, as the duration of the experiment is finite, by choosing p and q sufficiently large it is possible to obtain a driving which is effectively quasiperiodic on the time scale of the experiment. Thus, in the experiment of Ref. [11], the transition from periodicity to quasiperiodicity was studied by increasing p, q , so to make the driving effectively more and more quasiperiodic. The measurements across the transition revealed a qualitative change in the conditions on the driving force parameters for which a ratchet current was observed. Such a change precisely corresponded to a change in the symmetry of the system. This observed change in the system symmetry

The first rocking ratchet for cold atoms was experimentally demonstrated in 2003



▲ FIG. 3: (middle panel) Arrangement of laser fields which produce a 1D dissipative optical lattice, with blue arrows indicating the laser beams' directions and the red ones their polarizations; (up) close-up view of the laser set-up; (down) overall view of the experimental set-up.



was found to be consistent with the expected change in the effective dimensionality of the system, in agreement with the fact that the phases $\omega_1 t, \omega_2 t$ are effectively independent variables in the quasiperiodic limit.

Conclusions

This article reviewed recent experimental realizations of ac driven ratchets with cold atoms in optical lattices. Such a system allowed us to demonstrate several different ratchet schemes, and to investigate their fundamental properties. In particular, rocking and gating ratchets were demonstrated, and the transition from periodicity to quasiperiodicity was investigated in one of such systems. Although not discussed here, two-dimensional rocking ratchets for cold atoms have also been demonstrated [12], and new higher-dimensional rectification mechanisms revealed. This should also pave the way to the study of ratchet control of vorticity, a feature only present in higher dimensional systems. ■

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About the author



Ferruccio Renzoni studied physics at the University of Pisa, Italy (M.Sc. 1993) and at the Technische Universität Graz (PhD 1998). He then spent two years at the University of Hamburg and three at Ecole Normale in Paris, where in 2003 he obtained his “Habilitation à diriger des recherches”. Since 2003 he is at University College London, where he is a Professor of Physics.

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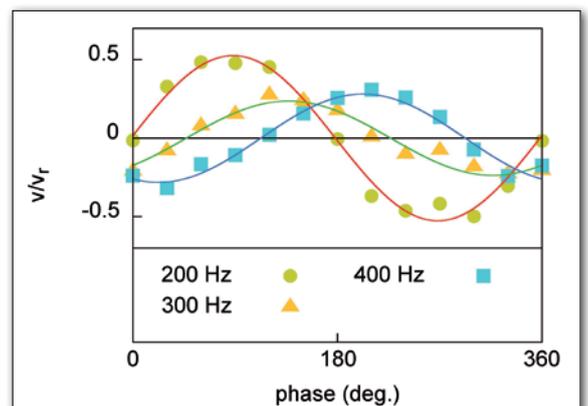
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THE ROLE OF THE SYMMETRIES IN AC DRIVEN RATCHETS

Consider a Brownian particle in a spatially periodic potential. A time-dependent force F , of zero mean, is applied to the particle. The aim of the symmetry analysis is to determine the conditions for the equation of motion to be invariant under the transformations which map a trajectory into one with opposite momentum. Clearly, if the equation of motion is invariant under one of such transformations, trajectories with opposite momentum are equivalent and directed motion is not possible. To proceed further, one has to specify the general form of the potential and of the driving. We consider the case of a spatially symmetric periodic potential, as this is the case relevant to the experimental realizations reviewed in this work, with the symmetry of the system controlled by the ac driving. Specifically, we examine the case of a bi-harmonic driving force $F = A\cos(\omega t) + B\cos(2\omega t + \varphi)$. We first consider the dissipationless case, in which there is no friction mechanism which damps the particles' motion, which will then be extended to include weak dissipation. The relevant symmetry here is the time-reversal symmetry. For the case of a bi-harmonic drive, and neglecting dissipation, whether the time-reversal symmetry is broken depends on the value of the phase φ : for $\varphi = n\pi$, with n integer, the time-reversal symmetry is preserved, while for $\varphi \neq n\pi$ it is broken. Therefore for $\varphi = n\pi$ current generation is forbidden, while for $\varphi \neq n\pi$ it is allowed. Perturbative calculations show that the average current of particles is, in leading order, proportional to $\sin(\varphi)$, in agreement with the above symmetry considerations.

In the case of dissipative systems, the time-reversal symmetry is broken by dissipation. Therefore also for $\varphi \neq n\pi$ the generation of a current is not prevented, despite the symmetry of the driving. The generated current I still shows an approximately sinusoidal dependence on the phase φ , but acquires a phase lag φ_0 : $I \sim \sin(\varphi - \varphi_0)$. Such a phase lag is the signature of dissipation-induced symmetry breaking.

▼ FIG. 4: Experimental results for the average atomic velocity in units of the recoil velocity v_r (equal to 3.52 mm/s in the present case), as a function of the phase φ between harmonics of the drive. Different data sets correspond to different scattering rates. The data are labelled by a quantity proportional to the scattering rate, reported in the bottom part.



Lyrics about Physics

■ Tatiana Balachovsky - Curator of the Kapitsa Museum - DOI: 10.1051/epr/2012106

Many years ago, in the early 60's, when I was about 11 years old, my classmate and I went to a far-away pharmacy after school. I no longer remember what took us there: perhaps we were planning to do chemical experiments, that required manganese and ammonia.



◀ Front of the Kapitsa Museum in Moscow

It was a cold bright winter day. The walk was quite long. Over half way through, we were so cold that we no longer wished to buy anything. Then my friend suggested that we drop by her cousin's grandfather to get warm. We turned and walked through an iron gate, through a snow-covered park, past a frozen pond and walked into his house. After climbing wooden stairs to the second floor, we found ourselves in the study of Peter Kapitsa.

Low winter sun shone through the room, and dust particles played in its golden rays. The whole space seemed fabulously beautiful. The study distinctly smelled an aura of professor - books, expensive leather furniture and a bit of tobacco. Piotr Leonidovitch no longer smoked then, but his pipe and a pack of good tobacco were always on his desk.

The change from the wintry streets was such that I stopped noticing

details and sank into feelings, amazing ones. Taking upon himself the responsibility of an academy member, Kapitsa decided that the girls should get warm and poured a tiny glass of liqueur for each of us. Until then, I had never tasted alcohol. The sweet Benedictine was flowing into my relaxed body. It was one of the most memorable impressions of my childhood.

Years later, destiny brought me into the same room, by then a museum. The same low winter sun shone through the room. Piles of marked up papers looked just the same. (Kapitsa had kept working on papers till his very last day.) Paintings, porcelain figurines on the chimney shelf, numerous crocodiles were all around - Crocodile was the nickname of Ernest Rutherford, Kapitsa's mentor and senior peer.

Today I am the director of the museum of Kapitsa. The more I learn about Kapitsa's life, the more I appreciate the scale of his personality.

In 1920 the young promising scientist lost his whole family - wife, two babies and father - to the influenza epidemic, so called "Spanish flu". It was the first major blow to his life - the first, but not the last. To help him keep living, his friends and colleagues sent him to Rutherford's laboratory at Cambridge. From 1923 Kapitsa worked at Cambridge, in Rutherford's laboratory. He met a Russian girl named Anna Krylova, who became his second wife and remained the person closest to him for the rest of his life. They built a home and had two sons. His experiments in cryogenics were so successful that in 1930 the Royal Society gave a special grant to the University of Cambridge for building a laboratory for research in low temperatures. On February 3, 1933, the laboratory was inaugurated with great pomp. His scientific prospects seemed unlimited. However, another blow was in the waiting.

In the summer of 1934, when Kapitsa was visiting the Soviet Union to see his mother and take part in scientific conferences, he was not allowed to go back

▼ Piotr Kapitsa in 1929





▲ The office of Kapitsa as preserved in the museum

to England and was forced to establish a scientific laboratory in Moscow. After months of negotiations between the Soviet government on one hand and Rutherford and the Royal Society on the other, the cryogenic equipment of Kapitsa's laboratory was transferred from England to Moscow. This is how the Institute for Physical Problems was created. Kapitsa became its head and continued his research in cryogenics. His family moved from England to Moscow and they begin a new life in the Soviet Union. Soon, Kapitsa set up production of liquid oxygen. He saw and corresponded with highest officials of the country.

Kapitsa worked successfully until 1945, when the attention of the world, and especially that of physicists, turned to the problem of the atomic bomb. In the Soviet Union, the atomic project was supervised by the head of the KGB Lavrentiy Beria. Beria brought together the most prominent scientists and invited Kapitsa too. But Beria knew nothing about physics, and Kapitsa refused to work under him. The payback followed right away: Kapitsa was removed from all of his positions. Perhaps, he was lucky to have survived at all (*it's important to say, that in the Soviet reality "invited" meant "forced to" while "to refuse" meant virtually "to commit suicide". So, the fact that Kapitsa and his family survived was a kind of miracle*). For the third time, all he has achieved was destroyed. And, for the third time, Kapitsa managed to survive the blow, start from scratch and succeed again. Kapitsa spent eight years in disgrace. Most of the time he lived at his dacha outside Moscow. There, in a shack, he

▼ Kapitsa living-room in the museum



set up a laboratory and kept working. After a while, his closest aide joined him, and his sons too were helping their father.

Upon the end of Stalin's era, Kapitsa returned to his institute. From then until his death in 1984, he lived in the mansion deep in the park, where I began my story. The Institute of Physical Problems was again an oasis in the minds of students. His home saw not only scientists of all stripes and colors, but artists, poets, musicians too were frequent guests in the mansion. *How could one have a mansion in Moscow in the sixties? It was exceptional. It was Kapitsa's caliber that made it possible.* After Piotr Leonidovich passed away, the Academy of Sciences decided to preserve his study as a memorial museum. Kapitsa's widow, Anna Alexeevna did a lot to help. She managed to create the effect of presence – it seems as if he has just stepped out and is about to be back. Yet, the exhibit shows the entire life of the scientist, both his moments of his international fame and his dark days of scary prospects, when some of his friends would cross the street to avoid him.

The museum contains the pieces of scientific equipment which Kapitsa was working with for many years. Part of it came here from Cambridge, another part was created with Kapitsa own hands. He was not only scientist, but a practical engineer, and was fond of designing things. Among the museum masterpieces there is a wooden table that never staggers.

In the museum, one can see instruments and devices, both those from Cambridge, and those made later in

Moscow. Among them are unique delicately made glass pieces with which superfluidity of liquid helium was discovered and studied.

Outstanding experimentalist, Kapitsa was handy and loved making all that might be needed, whether devices or furniture. One of his hobbies was repairing antique clocks. Therefore, the exhibit takes shows a lathe and, by it, a little *clock lathe*. Also there, is a specially designed wooden table that does not wobble, no matter how uneven the floor, that he made at his dacha in 1948.

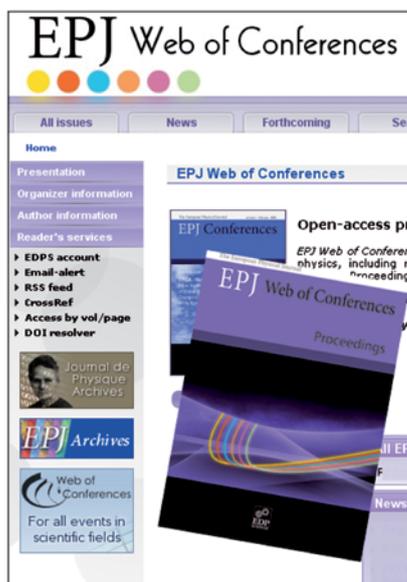


▲ The museum-kept nitrogen and oxygen liquefier of Kapitsa

Among the rest, the exhibit shows a unique collection of photos of prominent people, most of them autographed. Back in England, Kapitsa began to share photos with his fellow physicists. Above his desk was a whole portrait gallery of scientists. Photos of other famous people were added later. For example, in 1946 the leader of Yugoslavia, Marshal Tito arrived in Moscow. He visited Kapitsa's Institute and soon sent Kapitsa his autographed photo. When many years later, in 1966, Peter Leonidovich visited Yugoslavia, President Tito received him and awarded him the Order.

A lot of other medals and diplomas are displayed in the museum, reflecting an enormous global recognition of Kapitsa - a scholar and public figure, among them is the Nobel prize certificate, he obtained in 1978. ■

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