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International Year of Astronomy
2008 Nobel Laureates in Physics
Ion-beam cancer therapy
Nuclei "at the top of their shape"
Museum of Science of Coimbra

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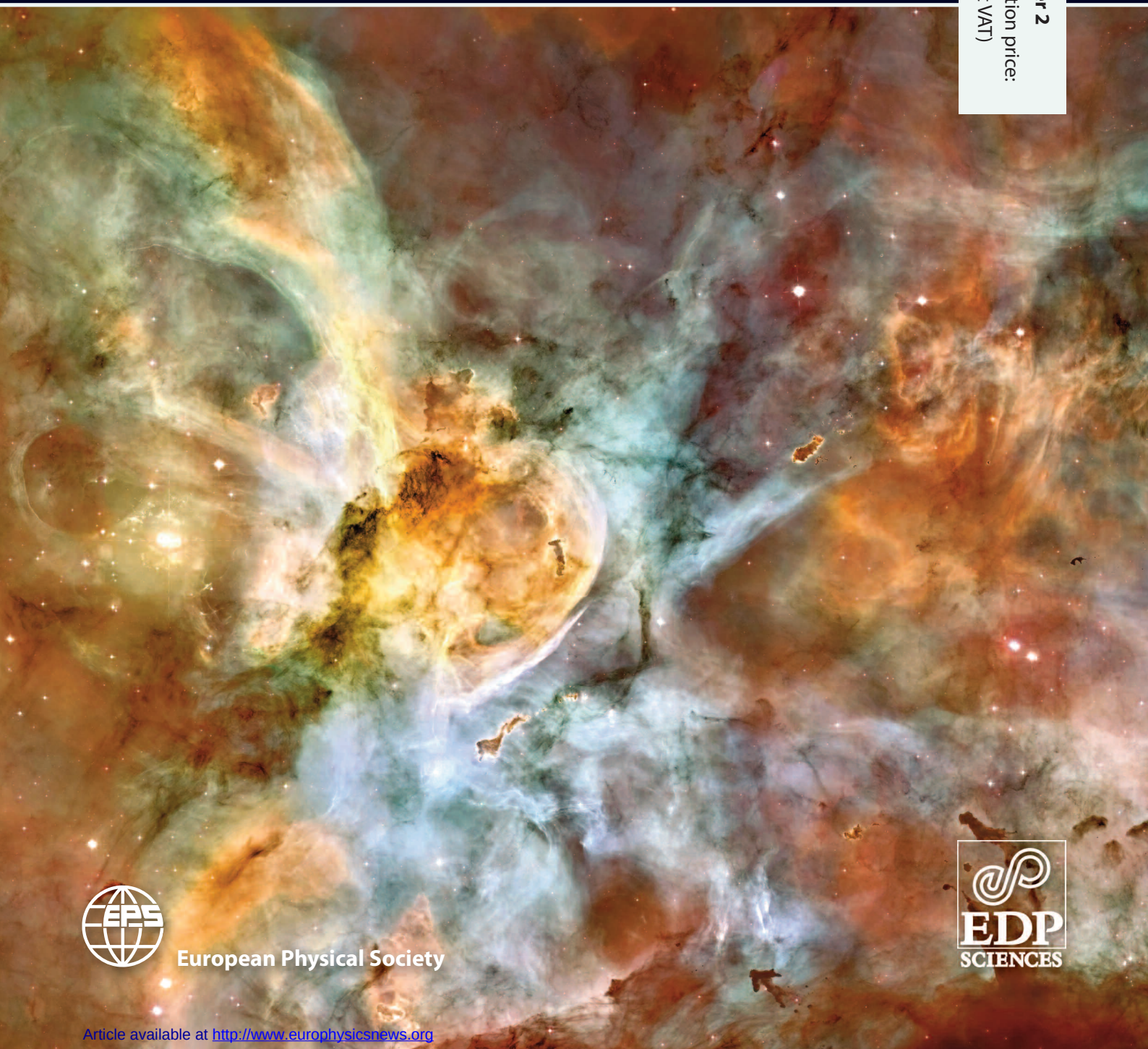

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Cover picture: This image, released for Hubble's 17th anniversary, shows a region of star birth and death in the Carina Nebula. The nebula contains at least a dozen brilliant stars that are 50 to 100 times the mass of our Sun, and the massive, unstable star Eta Carinae. © NASA - ESA - Hubble Telescope

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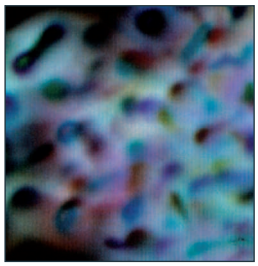
International Year of Astronomy



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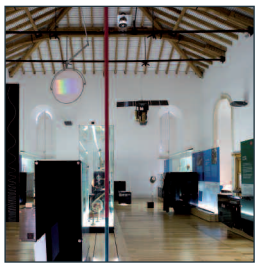
Nuclei "at the top of their shape"



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ACHIEVEMENTS AND CHALLENGES
IN FIVE NOT SO EASY QUESTIONS

Is EPS a society with vitality?

A clear YES! The EPS Divisions and Groups are involved in the organisation of about 90 conferences which attract speakers and participants from all over the world. The frontiers of our knowledge are expanded and careers in physics often begin with an invited paper at one of the EPS conferences. Divisions and Groups are aware of their responsibility that the careers of female physicists are partly in their hands and act correspondingly.

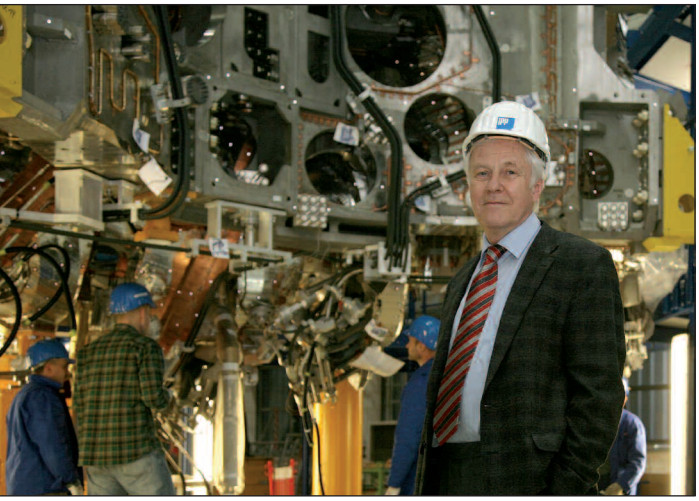
The divisions take care that the reputation of physics and physicists grow by awarding some of Europe's most prestigious prizes and medals. The foundation of respect by others comes first from self-respect. This grows via the recognition by peers.

Divisions and Groups are constantly renewing their Boards, often integrating younger. EPS Divisions and Groups evolve not only to keep abreast of new fields in physics but also to adapt to changing circumstances. This is a bottom up process. One recent example is the request by the Joint Astrophysics Division to be disbanded. This has led to the creation of the Solar Physics Division and the absorption of activities and topics of the Joint Astrophysics Division into the High Energy and Particle Physics Division.

Another sign of EPS' vitality is enhanced cooperation with other European learned societies most recently with the European Chemical and Molecular Society (EuCheMS) and the European Material Research Society (EMRS). Our joint activities will allow us to identify novel topics at the interface of chemistry and material sciences to consider joint divisions and groups.

Executive Committee and Council have looked at the activities of Action Committees and updated their objectives. Because of its historical importance, it was difficult to close the East-West Task Force. But the successful integration of the Eastern European countries into European science structures required a new vision. EPS now concentrates on the Member Societies that are not part of the EU or are our neighbours beyond the European borders, including the countries south of the Mediterranean. Last year, the EPS provided financial support for conferences and workshops in Mexico, Cuba, Cameroon, Palestine, Brazil, Bénin, and Uruguay providing travel support for invited speakers and financing poster prizes for young students.

Vitality also implies recognising challenges and responding to them. We have started an energy initiative, approaching - where they existed - similar groups in EPS Member Societies. For those Member Societies without energy groups, we encouraged their foundation. This European network has allowed for wider dissemination of the national energy reports.



Another collaborative effort with regard to energy will be the joint organisation of the European Energy Conference Series together with our partners (EuCheMS, EMRS, ESF). The first conference is scheduled for April 2010 in Barcelona.

The EPS is also working on the creation of the Large Facility Technology Network, which will bring together researchers ad project managers, allowing them to exchange knowledge in specific technologies, in project management and project tools, in the availability of test facilities or surplus equipment, and to share the experience on suppliers. The network would also make projects aware of colleagues outside the own field who could help in design reviews and intensify thus cross-fertilisation between research areas. One may question whether EPS should undertake the task of creating this network. The observation is, however, that often physicists assume project management duties and return to their science with the project after its completion.

Vitality implies communication. We have improved the contacts both to the Member Societies and the Divisions and Groups. The parallel session structure of the Council should prevent the one-sided monologue and replace it by a more inspiring communication format. In the frame of Member Societies with "preferential relation" (strong involvement in EPS budget, see below, publications, joint projects…) we meet twice a year with different composition adapted to the agenda. At every Executive Committee meeting, we meet at least the hosting Member Society to discuss in detail how to improve cooperation and communication and better understand the situation in that country. It should also become standard practice for the EPS President to be invited to Member Society business meetings. Vitality also means openly approaching others. We have analysed which societies can help us to meet our duties better and started a dialogue. We have a joint support project with APS (SESAME, Damascus, Syria), a joint visiting scientists project with the Chinese Physical Society and we will organise a joint conference with the Association of Asian Pacific Physical Societies in Japan in 1010.

Do others appreciate our vitality? I believe so but to find the appropriate qualifier is difficult. I take the growth of interest for EPN, our news magazine. Downloads have increased by a factor of 5 between January and December 2008.

Is EPS financially sound?

The annual budget of EPS is about 1.1 Million Euros. Its income is derived principally from it Members, publication activities, and conference organisation. DPG and IOP provide nearly 30% of EPS budget and I want to thank them for providing funds for the benefit of physics in Europe that EPS can spend according to its mission.

EPS is not a wealthy society and one has to keep in mind that each Euro spent for a European activity is of lower buying power than one spent for a national goal. For example, a meeting with participants from around Europe is more expensive than a national meeting. EPS also has a clear concept on how to meet its responsibility as a society with long-term goals and as an employer. The reserves of the Society are at a justifiable though still at the lower level within a reasonable corridor. The Executive Committee has decided to further build up the reserves. If necessary however, reserves will also be available to undertake important short-term activities.

A topic in this year was a unit-fee increase. In addition to an inflationary increase, the Executive Committee also considered a change in the modality for future increases. It is necessary to consider whether we should move away from the current system increases after a few years, which always trigger fundamental debates at the wrong occasion to a continuous and standard correction of inflation. The Executive Committee has decided not to pursue the unit-fee increase but to first assess the impact of the present financial crisis on EPS activities and its members societies. The change in modality should, however, stay on the agenda.

Is EPS attractive for new members?

New Member Societies are Liechtenstein and Luxemburg. A major initiative is to increase the number of EPS Associated Members. All physics institutions with a European scope should be member of EPS. The Large Facility Technology Network should be another incentive for joining EPS.

EPS would benefit from increased membership in Member Societies. This can be achieved in part by developing network of school-teachers and university deans to get

into contact with bright pupils and physics freshmen. No-fee or cheap membership programmes for an initial membership period have been the key to success in some Member Societies. EPS can help the Member Societies by adding the aura of international prestige and recognition in physics when courting pupils and students. EPS and Member Societies should also cooperate to gain Individual Members for EPS. A win-win proposal is on the table.

Is there a need for EPS in the future?

Of course a clear YES – more than ever! EPS celebrated its 40th anniversary in 2008 and can be proud of its achievements and services in the past and it is mature enough to face the coming challenges and tasks. The importance of science policies and funding at the European level will further grow. The financial frame for research grew from less than 20 to more than 50 Billion Euro from the 6th to the 7th Framework Programme. One can bet whether FP-8 will hit the 100 Billion Euro ceiling. Europe has an excellent research infrastructure, and the European Commission is becoming increasingly relevant for physics funding; the founding of the ERC and its first actions are an additional incentive and encouragement.

In the process of European integration, the national borders will lose importance. The Bologna university reforms – irrespective of their appropriateness to physics education –follow the logic of the Schengen and Maastricht agreements – open borders, credit points instead of passports, Euros instead of wallets full of currencies. New regional centres will develop – around the Baltic Sea, east and west of the Rhine, in the triangle Switzerland, France and Germany and elsewhere. I hope that the measures which are presently taken to cope with the economic crisis will not turn back the wheel.

Europe - not a single member state - must withstand the global challenges. In this process of reorientation and refocusing toward global objectives, EPS will play an important role together with its MS. This process must be carried out jointly not by competing with each other. EPS does not stand outside the circle of its Member Societies but is part and amidst of them specifically established (and funded) to carry out the European and trans-European objectives of its members as defined regularly by its Council.

Is the work mostly done?

This time a clear NO! EPS must further develop its service capabilities. Above all, it must develop and continuously update member data bases and data basis for its political incentives. It must continuously demonstrate to its members – Member Societies, Individual or Associated Members – the value of the membership. EPS must be the forum which disseminates news of relevance for physics research and education. Each physicist from Europe or elsewhere must know that EPS is the place to go to get professional advice. Membership must be rewarding – immediately and on a lasting basis as well.

EPS and Member Societies must cooperate better to offer the best product to their clients. One example is conference organisation. One should discriminate between large international conferences that should be organised by or carried out in cooperation with EPS and small ones that follow a more national agenda and where national and educational aspects play a larger role. Though Europe should maintain and further develop world-class conferences, it should also be open for arrangements with APS or AAPPS to form international conference series, like the EPS Accelerator Group did it in case of IPAC.

Major issues for the future include physics teaching at the school level. EPS, specifically its Physics Education Division, but also interested and capable individuals in its structures are involved in many educational activities – Master Classes, Physics Olympiads, teacher education and other activities. Nevertheless, we witness a continuous decline in education in mathematics and the natural sciences. In several countries there is even the threat that physics is replaced in school curricula by a subject called "integrated natural sciences". Such a development might be accelerated due to the absence of sufficient physics teachers and by the overall disregard of physics by the public. In such an atmosphere, our field could suffer an irreversible damage. The writing is on the wall.

A single political action to highlight this severe trend in education is not be the right answer. The topic of appropriate physics education of pupils has to remain on the agenda. I must admit that I am very sceptical of a turn-around of this negative trend. The handling of the present economic crises does not give me much hope. Many governments propose now to refurbish run-down schools and university buildings. It is a shame that the motivation for these measures is their rapid implementation and possible impact on the economy and not the need to create an attractive environment for those engaged in education and those educated to lead the future. It is cynical but one is led to hope for further crises of this sort considering their collateral benefits.

Another ongoing and future topic is physics publication. In Europe, we enjoy about 350 journals – 10 times more than in the USA. This opulence is a weakness; the journals are cannibalising each other. In the letter category, we are on the way to a US monopoly. Our friends from APS and AIP agree that monopolies are bad in the end. It should be highlighted that journals also play a role in making science policy. We must be involved and we must maintain the balance, otherwise, Europe is on the way to a "Knowledge Society" with copyright in the USA.

EPL will continue its upward trend in the number of papers submitted and impact factor continue to reduce the acceptance rate. The proposal of a Physics Publication Platform is on the table that would allow a concentration of publications, the creation of tools or physics research, and a clear separation between the economic interests of publishers and the scientific interests of EPS.

Industry is potential employer of physicists; representatives with industry background introduce different perspectives and connections that a learned society needs to represent the whole community. EPS will have to look more into the role industry plays in its structure and governance. Perhaps EPS has to define an Industry Membership, organise this group and award it institutional rights. Another societal trend, which affects specifically physics is that the notion of the actual capabilities of a physicist might get lost. How should a psychologist, charged to find new staff, deal with the PhD thesis of a high-energy-theorist? For employers and professional head hunting agencies the physicist is frequently seen as an eccentric whose place is exclusively in research. A better integration of industry within EPS (but also within Member Societies) might prevent the loss of professional identity.

How should EPS position itself toward the strengthened European political structures? The contacts to politicians are vital but also tempting. One has to suppress, however, the temptation by being surrounded or possibly even accepted by those who represent power. EPS should not carry out lobbying work but should resort to its qualification as a Learned Society which represents the knowledge and understanding of more than 100 000 physicists in Europe. Evening invitations in Brussels and Strasbourg in the classical format of "dinner plus speech" are useless. We try to stay in contact with members of the European Parliament, specifically those from the ITRE committee; we enjoy good relations to the European Economic and Social Committee and we try to meet the relevant Commissioners and the Science Ministers of the respective EU presidency (I must admit without much success). We must continue to be responsive to all calls coming from the Commission where EPS can give expert advice. In this way, the reputation and confidence in EPS as partner for the Commission will grow.

For short-term and critical moves, which are often not addressing physics specifically but natural sciences at large, we should cooperate with other EU Learned Societies, specifically EuCheMS and EMRS. Joint efforts may have more impact but, on the other hand, lead to split responsibilities. The voice of the individual may be ignored or even suppressed. EPS must continue developing an atmosphere where specifically the individual can raise her or his voice and where volunteers are attracted because they can realise their ideas and can witness the effects of their engagement within the Society.

My term as President of the EPS ended in March 2009. I enjoyed working with distinguished scientists who love physics and are devoted to Europe – its values and cultural traditions, and who invest some of their spare time to help physicists and to promote physics in Europe. My specific thanks go to David Lee, the Secretary General, and his staff at Mulhouse. ■

Friedrich Wagner,
past-president of the EPS

JOHN BEEBY (1937 – 2009)

John Beeby, who had been the EPS Treasurer from 2006, died on 4 January.

He had long been a strong supporter of EPS having served previously as Chair of the Surface and Interfaces Section of the Condensed Matter Division and as representative of Individual Members on EPS Council. John was ardent proponent of Individual Membership of EPS and was delighted to become one of the first EPS Fellows in 2005. John was also Honorary Secretary of the Institute of Physics from 2003 and gave absolute commitment to both IOP and EPS, with unquestionable integrity and with wisdom based on long experience.

As an academic he had a brilliant undergraduate career in Clare College, Cambridge. Following his PhD in solid state physics he was an ICI research fellow at University of Manchester, then a research associate at University of Illinois. Joining the UK Atomic Energy Research Establishment at Harwell in 1965 he became a Principal Scientific Officer, and spent a year at University of California (San Diego) before being appointed to the Chair of Theoretical Physics at University of Leicester in 1972. While there he became Head of Department, Dean of Science and Pro-vice Chancellor. In 1995

he was awarded the Glazebrook medal of the IOP for outstanding research. He retired in 2002, but as an emeritus professor at Leicester he continued in research, visiting the physics department twice a week and continuing to publish in surface science.

Apart from his great love for his family and physics, any spare love he had was applied to Rugby and the Leicester Tigers – of which he was a member for 35 years. He played rugby in his youth. Back injury brought his playing to an end but he remained a serious rugby fan When away on EPS matters after work was finished if there was an important match he liked to find an Irish pub where he could watch it live, often accompanied by David Lee. John is survived by his wife Ginny, with whom he would have celebrated their 50th wedding anniversary in June, by their sons, Ian, Christopher and Martin and six grandchildren.

John has left EPS with a masterful analysis of the future financial situation and has built a plan of action which we can follow. John was a true European and an excellent advocate for the European Physical Society. He will be sorely missed. ■

Tony Scott and **Peter Melville**

Meeting Point of Optical Technologies in Europe

The EPS Quantum Electronics and Optics Division will organise the next edition of **CLEO®/Europe – EQEC** at the International Congress Centre Munich from 14 to 19 June 2009. CLEO®/Europe is one of the conferences in the World of Photonics Congress together with, LiM 09 Lasers in Manufacturing, Optical Metrology, Frontiers in Electronic Imaging, Manufacturing Optical Components, European Conferences on Biomedical Optics (ECBO) and Medical Laser Applications.

LASER 2007 - World of PHOTONICS - © AlexSchelbert.de

It is the leading technical congress for optical technologies in Europe and is ranked in the top 3 world wide.

In 2007 3,100 attendees from around the world took part. 2,300 lectures, presentations and posters were presented.

In parallel to the Congress the LASER World of PHOTONICS, international trade show for components, systems and applications of optical technologies, takes place and facilitates a unique exchange between scientific and industrial sectors.

To bridge the gap between theory and practice the World of Photonics Congress will also feature a programme of practice panels at the forums in the exhibition halls. They cover the areas of Biophotonics and Life Sciences, Advanced Laser and Light Generation in Science and Industry as well as Lasers and Laser Systems for Production Engineering.

For more information, please visit:
www.cleoeurope.org or www.photonics-congress.com

LISE MEITNER PRIZE

The European Physical Society awarded, through its Nuclear Physics Board, the Lise Meitner Prize for Nuclear Science 2008 to professor Walter Greiner and professor Reinhard Stock.

Both recipients are from Johann Wolfgang Goethe-Universität and Frankfurt Institute for Advanced Studies, Frankfurt. Medals, diplomas and checks, sponsored by CANBERRA, France, were presented to the recipients during a special session of the International Symposium on Heavy Ion Physics 2008 at GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany, on November 19th, 2008.

Reinhard Stock and **Walter Greiner** were jointly honoured for their outstanding contributions to the development of the field of relativistic nucleus-nucleus collisions, more precisely the physics of hot and compressed nuclear matter. This field uniquely bridges nuclear and particle physics with further connections to astrophysics and cosmology. Nucleus-nucleus collisions are a unique means of creating, under laboratory conditions, matter at extremes of energy density, pressure and temperature, comparable to the conditions of the early stages of the universe.

Reinhard Stock has played a seminal role in developing this field by his decades-long involvement in the sciences, pushing the innovative use of high-energy accelerators and the necessary technical developments.

▲ Lise Meitner Prize ceremony.
From left to right: Matti Leino, Walter Greiner, Marie Odile Lampert (CANBERRA), Reinhard Stock, Hartwig Freiesleben (Chair, Lise Meitner Prize Committee). © G. Otto GSI

He was one of the initiators of the physics programme. **Reinhard Stock** was the driving force behind the GSI/LBL initiative to convince CERN to engage in a relativistic heavy ion programme in the 1980s with the result that oxygen and sulphur beams with energies of 200 GeV per nucleon became available at the SPS in 1986. He deserves the credit for finding extra budgetary funds for developing a lead ion source and the upgrading of the SPS injector. Under his leadership, the NA49 collaboration built the then biggest time projection chamber, integrated it into a large acceptance spectrometer and started data taking in 1994. While the CERN experiment was still in full swing, **Reinhard Stock** joined the efforts to start a similar programme at RHIC at BNL where he played a vital role in the STAR experiment. From the very first, he stood up for the heavy ion physics programme at LHC and was instrumental in organising the German participation in the ALICE experiment.

Reinhard Stock is well known for his remarkable leadership of large and complex experimental projects, and even more so for his important contributions to physics, namely the proof of the existence of collective flow indicative of the nuclear equation of state via compression and heating of nuclear matter, the statistical interpretation of particle ratios with emphasis on strange particles, Bose-Einstein correlations to probe the space-time-properties of the reaction volume, and the fluctuations of event-by-event observables.

In the early 1970s **Walter Greiner** put forward the idea of the occurrence of shock waves in relativistic nucleus-nucleus-collisions. Shock waves are considered to be the key mechanism for compressing and heating of nuclear matter. Compression and heating of nuclear matter is the only means of investigating the nuclear equation of state (which relates pressure, density, and temperature of nuclear matter) and, in particular, the possible phase transition into quark-gluon matter. He also advanced the idea that the appearance of collective flow phenomena is most directly related to the properties of the nuclear equation of state. This equation plays a crucial role in the evolution of the universe, in supernova explosions and thus in the production of heavy elements, and in the stability of neutron stars. **Greiner** and his school predicted novel hydrodynamic effects such as bounce-off and squeeze-out of nuclear matter.

Walter Greiner's ideas have inspired experimental studies of nuclear matter at extreme conditions of temperature and density and have therefore had a decisive influence on the development of this field of physics. Today, shock waves and collective flow are well-established properties of relativistic nucleus-nucleus collisions. Hydrodynamic effects were discovered – and are still being found at all relativistic energies from LBL and SIS18 at GSI to the SPS at CERN and at RHIC/Brookhaven. These phenomena turned out to be unique quantitative barometers for the pressure measurements still being performed today. In 2000, after many years of data taking by several groups, as one culmination, the experiments using a lead beam at CERN presented compelling evidence for the existence of a new state of quark-gluon matter in which quarks are liberated to roam freely. Formation of quark-gluon matter has been tentatively confirmed by results obtained at the RHIC at BNL. ■

Matti Leino,
University of Jyväskylä
Chairman, Nuclear Physics Board

THE UNIVERSE — YOURS TO DISCOVER

INTERNATIONAL YEAR OF ASTRONOMY

▲ **FIG. 1:** (upper image) The Milky Way seen above the Alborz mountain range in northern Iran and (lower image) the star-free sky of metropolitan Teheran. © Babak Tafreshi

When Galileo Galilei, in 1609, for the first time looked at celestial objects through a telescope, astronomy changed forever. To celebrate the 400th anniversary of this event, the International Astronomical Union (IAU)[1] persuaded the United Nations (UN) to declare the current year as the International Year of Astronomy (IYA2009).

The *IYA2009* is by now well underway. IAU has given it a structure with eleven '*Cornerstones*', and has set up 136 *National Nodes*. The IAU thus has formed the largest public education network ever established for outreach. National Nodes are the groups that coordinate *IYA2009* activities in a given country. The nodes of all participating countries can be found through the URL www.astronomy2009.org/organisation/nodes/national/. Interested persons will there find out, which events and activities are offered in the framework of *IYA2009* in their area — where and when.

The *Cornerstones* are global programmes with specific themes designed to achieve *IYA2009*'s main goals, whether it is the support and promotion of women in astronomy, the preservation of dark-sky sites around the world or educating and explaining the workings of the Universe to millions. Some examples are:

Galileo scope

The *Galileoscope* Cornerstone has the aim to offer to ten million people their first look through an astronomical telescope in 2009. This is possible if, for example, 100 000 amateur observers each show the sky to 100 people.

The web site of *IYA* describes this experience and its consequences: "Who doesn't remember the first time they looked at the Moon through a telescope and were amazed by the details of the mountains and craters? … Observing through a telescope for the first time is an experience that shapes our view of the sky and the Universe. … The *IYA2009* programme wants to share this observational and personal experience with as many people as possible across the world."

A simple, accessible, easy-to-assemble and easy-to-use telescope has been developed and, according to the plans of *IYA*, will be distributed by the millions. Ideally, every participant in an *IYA2009* event should be able to take home one of these little telescopes, enabling them to observe with an instrument similar to Galileo's.

Dark Skies Awareness

Under the title 'The Vanishing Night' Klinkenborg (2008) wrote in the *National Geographical Magazine*: "For most of human history, the phrase light pollution would have made no sense. Now most of humanity lives under intersecting domes of reflected, refracted light, of scattering rays from overlit cities and suburbs, from light-flooded highways and factories."

note

[1] The IAU was founded in 1919, and now has nearly 10 000 individual members, all distinguished astronomers from around the globe. The Union is the world's largest professional body for astronomers. The IAU's mission is to promote and safeguard the science of astronomy in all its aspects through international cooperation. The IAU also serves as the internationally recognised authority for assigning designations to celestial bodies and surface features on them.

Indeed, the arc of the Milky Way seen from a truly dark site is immediately appreciated as part of our planet's cultural and natural heritage. The images of Figure 1 compare the view of the sky at two locations: on top, the Milky Way as seen above the Alborz mountain range in northern Iran and, below, the star-free grey sky over the city of Teheran — an astonishing difference. Today most city skies have become virtually empty of stars. Light pollution obscures the stars and interferes with astronomical observations. The loss of dark night sky for much of the world's population is a serious and growing issue that not only impacts astronomical research, but also human health, ecology, economics and, ultimately, also energy conservation. It is therefore urgent to preserve and protect dark night skies in places such as urban cultural landscapes, national parks and sites of astronomical observatories.

100 Hours of Astronomy

The *100 Hours of Astronomy* Cornerstone has already taken place in early April 2009. This was a four-day event designed to bring astronomy to the public everywhere. Global events were scheduled for every one of the four days. On the first day, 2 April, science centres participated in a live webcast, which featured current topics in astronomy. A live 24-hour 'Research Observatory Webcast' followed on 3 April, when astronomers at professional research observatories around the globe took viewers inside their telescope domes and into their control rooms. A global 24-hour star party took place on 4 April 2009, where both night-sky and solar telescopes were made available, free of charge, by astronomy clubs for public viewing. The goal was to allow as many people as possible to have a chance to look through a telescope. The 5th of April, the last day of the *Hundred Hours of Astronomy* Cornerstone, was a Sunday and appropriately was devoted to celebrate the Sun — our closest stellar neighbour, who supports our life on earth.

▲ **FIG. 2:** Stonehenge, a prehistoric monument located in the English county of Wiltshire, about 13 km north of Salisbury. The monument is among the most famous groups of megaliths in the world, and consists of circles of menhirs arranged in a pattern, whose astronomical significance is still being explored. Stonehenge is a UNESCO Heritage site. © IYA Website

Astronomy and World Heritage

This Cornerstone aims at identifying sites around the world that are related to astronomy, in order to preserve their memory. Apart from some of the well-known sites of this kind, namely the Pyramids of Giza in Egypt, the Mayan city of Chichen Itza in Mexico, and the Stonehenge monument (Figure 2) in the United Kingdom, astronomical heritage is currently under-represented in UNESCO's World Heritage List.

This *IYA* Cornerstone has already led to the 'Astronomy and World Heritage Initiative', which will officially recognise, promote and preserve astronomical sites that are of outstanding significance to humankind. Astronomical heritage will thus become much better represented in the World Heritage List and this will raise awareness of the cultural significance of astronomical sites, both ancient and modern.

She is an Astronomer

In concordance with the United Nations Millennium Development Goal of promoting gender equality and empowering women, this Cornerstone is designed to provide neutral information to female professional and amateur astronomers, students, and those who are interested in the gender equality problem in science, in general. Bias issues are tackled with the help of a web platform, which can be accessed regardless of geographical location and where information as well as links about gender balance and related resources are collected. *She Is an Astronomer* will thus promote gender equality in astronomy (and science in general) and also will help increase the interest of young females to study and pursue a career in astronomy.

On 15 and 16 January 2009 the organisers of *IYA* followed the same pattern as that used four years ago, when the European Physical Society launched the International Year of Physics (more frequently called the World Year of Physics, *WYP2005*): prestigious speakers and numerous astronomers gathered at UNESCO in Paris for the Opening Ceremony of *IYA2009*. Students from all over the world had been invited to help celebrate the opening of the *IYA*. The two-day event gave a magnificent overview of the wonders of astronomy and of the impact astronomy has had on humanity since ever.

For example, Franco Pacini, the astronomer, who originally promoted the idea of an *IYA*, addressed at the opening in Paris the influence of astronomy on civilisation. He quoted from *Naturales Questiones*, an early description of Nature, by Lucius Anneus Seneca: "if the stars were visible from just one place from Earth, people would never stop travelling to that place, in

order to see them." Fortunately, the sky is a common experience for humanity all around the globe. Pacini explained that people had always been fascinated by the stars and by celestial phenomena, and how different civilisations have projected their belief, their hopes and fears onto the sky. He then showed how astronomy, through mutual appreciation of such traditions, offers many opportunities to promote multicultural respect, especially among children.

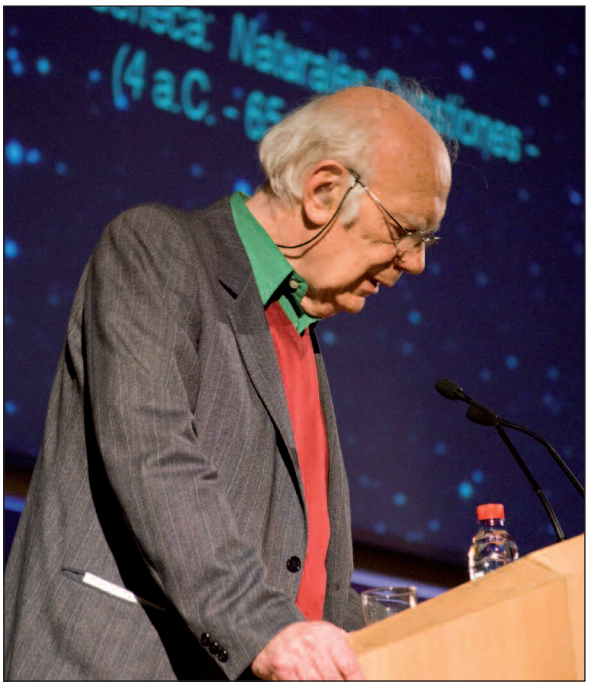
Lord Martin Rees gave an account of the cosmic evolution in a lecture entitled 'From a «simple» beginning to our complex Cosmos'. He described how our Universe started in a hot, dense and almost uniform state; how the first atoms were formed as the Universe expanded and cooled and how structures then emerged, leading to the formation of galaxies, stars and planets. Rees underlined the evolutionary aspect of recycling in the Galaxy with the memorable sentence: "We are the nuclear waste of the fusion, which makes stars shine."

Michel Mayor who, with Didier Queloz, had discovered the first exoplanet, *i.e.*, the first planet outside the solar system in 1995, discussed the unexpected diversity of the over 330 planets detected since his discovery. He also sketched the way still to go, before we can actually observe Earth-like exoplanets in the habitable zone around stars — where water is liquid — and investigate, whether such planets also harbour life like the Earth.

The President of the IAU, Catherine Cesarsky, stressed the motto of the *IYA*: 'The Universe — yours to discover', which reflects the intention of the *IYA* to support life-long learning. She also circumscribed the hoped-for impact of the Astronomy-Year by the maxim: "Through the *IYA* citizens of the world will discover their place in the Universe."

Koïchira Matsuura, the Director General of UNESCO — the UN lead agency for the *IYA* — concluded his opening speech by saying: "From World Heritage sites such as the ancient monuments of Stonehenge, to the most recent Hadron Collider experiment led by the European Organisation for Nuclear Research (CERN), which aims to throw light on the origin of the Universe, people have always looked to the sky for answers to the questions 'How did we get here' and 'Why are we here' ". With this he also indicated that astronomy nowadays goes well beyond the confines of a narrowly defined discipline and is longing for answers coming out of physics as well.

When Galileo observed the heavens with his telescope, our 'vision' had 'cleared' beyond that of our innate senses. He discovered the moons of Jupiter, which form their own 'solar system'; he also saw that the Sun had spots and thus was not the perfect sphere imagined by philosophical speculation. This was the start of a voyage into the remote past of the Universe, progressively nearer to its origin. We are now at the stage, where we can see objects, whose age, when they emitted the light that reaches us today, was only about ten percent of today's age of the Universe. ■



▲ **FIG. 3:** F. Pacini

Martin C.E. Huber, Switzerland, EPS special envoy to UNESCO opening of *IYA2009*

Reference

[1] V. Klinkenborg, Our Vanishing Night, *Nat. Geogr.* **2008/11**, (2008) • http://ngm.nationalgeographic.com/2008/11/light-pollution/klinkenborg-text

Conferences and Schools announcements

MICS'2009
The third international colloquium "Mid-Infrared Coherent Sources" (MICS'2009) will be held in Trouville/Deauville (Normandy, France), 8 to 12 June 2009.

Website:
www.mics2009.ensicaen.fr

DFT09
The 13th edition of the International Conference on the applications of Density Functional Theory in Chemistry and Physics - DFT09 – will be held from August 31st to September 4th, 2009 in Lyon (France).

Website:
www.dft09.org

ECOSS 26
The 26th European Conference on Surface Science (ECOSS 26) will take place in Parma (Italy) from August 30th to September 4th, 2009.

Website:
www.ecoss26.eu

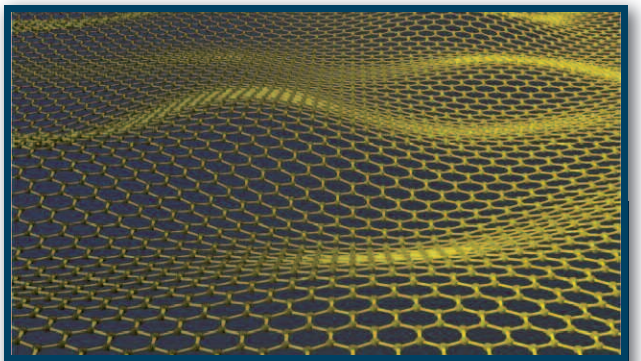
Graphene: the hard and soft faces of a material

When discovered by Andre Geim *et al.* in 2004, Graphene, the thinnest cloth in nature, was seen as an interesting curiosity. When its unusual quantum Hall effect (QHE) was demonstrated in 2005, a new field of research in condensed matter physics was created. Besides being one atom thick (although observable by the bare eyes), its electrons propagate as massless relativistic particles, the so-called Dirac particles, albeit with a velocity which is 300 times smaller than the actual speed of light.

Although the bonding between the carbon atoms in graphene is one of the strongest in nature (same strength as in diamond), the material is very soft because, just as it happens with membranes, it is very easy to bend it to create ripples, wrinkles, scrolls, creases, and folds (see Figure). However, unlike soft organic membranes that are electric insulators, graphene is a metal where the electrons propagate more easily than in silicon (because of that and its structural robustness, it is considered as a possible replacement for silicon in electronic devices). Therefore, it is a rare example of a metallic membrane and hence brings together concepts of soft and hard condensed matter physics.

In our paper we have shown that the electrons interact with the ripples of graphene: **1)** electrons are scattered by the ripples and, **2)** graphene's softness can be changed with the application of electric fields. This unusual state of affairs allows for the control of its electric properties through its structure. Hence, unlike ordinary semiconductors, where electronic properties are modified by the insertion of dopants (that also introduce disorder), electrons in graphene can be harnessed with "origami" and "paper cutting" techniques. However, this is still a field in its infancy that remains largely unexplored. ■

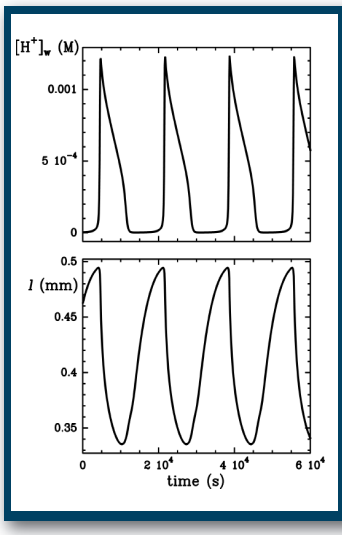
Eun-Ah Kim and **Antonio H. Castro Neto**,
'Graphene as an electronic membrane', *EPL* **84**, 57007 (2008)



▲ Artistic rendering of ripples in graphene

Can a gel spontaneously **oscillate in size?**

Can a gel spontaneously oscillate in size? We have shown theoretically that a polyelectrolyte gel immersed in a reacting medium, kept far from equilibrium by a constant feed of fresh reactants, can change shape with a regular periodicity. What is needed is a hydrogel which can swell or shrink as a function of the chemical composition of their solvent, such as a polyelectrolyte in response to pH changes.



◀ Numerical simulations of oscillations of *size l* and of $[H^+]$ in a one dimensional piece of gel. One tip is kept in contact with the contents of a continuous stirred tank reactor fed with the reactants of the Bromate-Sulfite reaction. The residence time is short enough for these contents to remain almost unreacted. Reaction takes place within the gel where the reactants diffuse from the tip. No-flux boundary condition (impermeable wall) are applied to the opposite tip, where the reported $[H^+]$ oscillations are monitored.

Combining such a gel with an autocatalytic chemical reaction can lead, through the coupling and mutual feedback of concentration, diffusion and swelling/shrinking, to an oscillatory instability, even when the surrounding medium is at stationary state. Our model accounts for the main transport, reaction, and swelling processes involved.

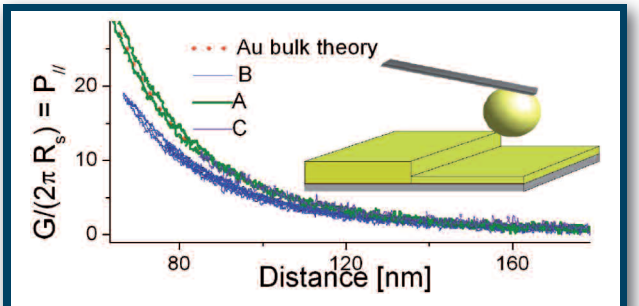
The prototypical Bromate-Sulfite reaction exhibits an autocatalysis with H^+. Whereas this non oscillatory reaction could only lead to stationary concentration distributions in an inert gel, we predict that, in a narrow domain of size, it can induce periodic mechanical and chemical pulsation in a pH sensitive polyelectrolyte gel: although the composition of the bath is stationary, the gel size and the composition in the core oscillate. These results, which are supported by preliminary experiments, pave the way for objects capable of autonomous motion driven by the chemical environment. ■

J. Boissonade,
'Oscillatory dynamics induced in polyelectrolyte gels by a non-oscillatory reaction: A model', *Eur. Phys. J. E* **28**, 337 (2009)

Non-contact **Casimir force** measurements

Quantum fluctuations of the electromagnetic field are known to produce a remarkable mechanical effect between two solids. Whatever their forms or their physical properties, there exists a long-range interaction between them, the so-called Casimir force named after Hendrik Casimir who predicted it in 1948. Casimir calculated the attractive force between two ideal mirrors in vacuum. Since then, this effect has attracted much interest in many areas such as micro- and nano-mechanical systems, quantum field theory and gravitation. The variety of boundary conditions that can be imposed to the electromagnetic field leads to rich phenomena and open questions about this quantum effect. With up-to-date techniques derived from Scanning Probe Microscopy the Casimir force can be precisely measured, but its absolute measurement together with the mirror's distance hides many instrumental difficulties. Our force machine provides a well-controlled and quantitative measurement of this force versus the mirror's distance. We have used it to further explore these boundary effects in the case of very thin films, which exhibit a Casimir skin effect (F. Capasso 2005). We use a gold-covered sphere, which is the probe and attached to the cantilever of the force machine. The second mirror is a plate with a flat structured gold film: the left and right part are 300nm and 10nm thick, respectively. As shown in the figure, the 10nm film produces a much smaller Casimir force than the 300nm film. In addition, measuring the Casimir force at different places on the 10nm film revealed large variations from place to place. Somewhat as a paradox, local measurements of the Casimir force could be seen as a sensitive tool to investigate changes in film properties that are not easily measured by others techniques. ■

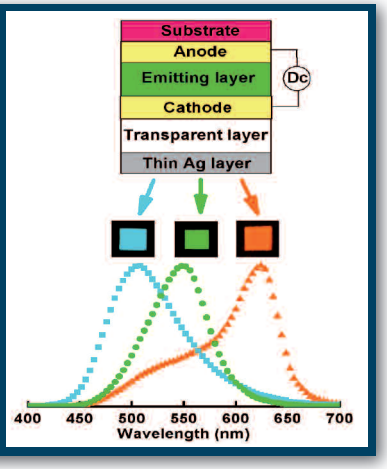
G. Jourdan, **A. Lambrecht**, **F. Comin** and **J. Chevrier**, 'Quantitative non-contact dynamic Casimir force measurements', *EPL* **85**, 31001 (2009)



▲ Casimir skin depth effect. Curve A is obtained from the thick part, whereas curves B and C are associated to two different locations of the shallow part.

Tuning emission color **of OLED**

Organic light-emitting diodes (OLEDs) are bright, emissive, colourful devices that offer low power consumption, wide viewing angle, good contrast, and video rate operation, and are considered as promising candidates for next-generation flat-panel displays. Full colour display can be realized with red, green and blue pixels in which different organic emissive materials are used as the light-emission layer. An alternative approach is white OLEDs combining with colour filters. However, these filters are very expensive, increasing the manufacturing cost, and cause large light loss.



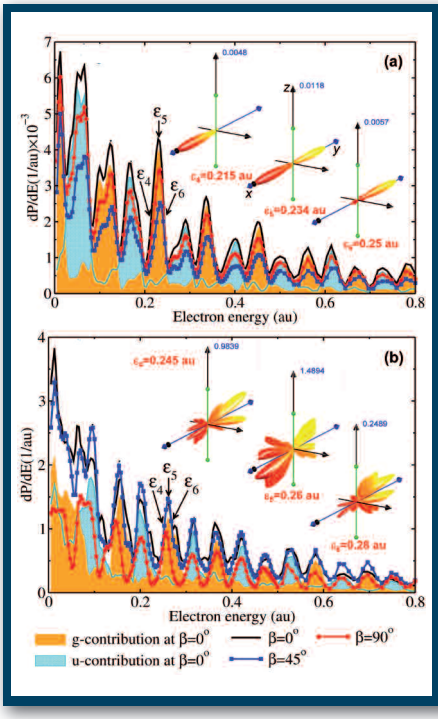
▶ Device configuration of the color-tunable top-emitting OLEDs. Different-color light from light blue to red can be emitted from this kind of OLEDs with the same emissive layer.

Our work explores the possibility to realize multicolour emission from the OLEDs with the same emissive layer via exterior tunable optical films. The OLEDs were built in a top-emitting structure with an emissive layer sandwiched between highly reflective bottom anode and semitransparent top cathode as shown in the figure. The top-emitting structure can provide a high aperture ratio of a pixel in display. Above the semitransparent top cathode, a multilayer tunable optical film is deposited to tune the emission colour by means of the microcavity effect between the highly reflective bottom electrode and the overlaid multilayer optical film. It can be seen that blue, green and red light can be emitted from the OLEDs with green fluorescent tris(8-quinolinolato) aluminum as the emissive layer. The advantage of this device configuration is that the emission colour of the OLEDs can be tuned via the exterior multilayer film, which does not affect the electrical characteristics of the underlying OLEDs. This may provide a way to realize full colour display from white OLEDs without filters. ■

J.H. Hou, **J. Wu**, **Z.Y. Xie**, **Q. Su** and **L.X. Wang**, 'Tuning the emissive colour of top-emitting organic light-emitting diodes by using exterior multilayer films', *J. Phys. D: Appl. Phys.* **42**, 035107 (2009)

Breaking symmetry **by intense fs laser pulses**

The simplest system exhibiting the chemical bond is H_2^+. Each electronic state possesses a specific inversion symmetry, gerade (*g*) or ungerade (*u*), with respect to the molecular center. Recent work show that symmetry breaking is possible in H_2^+ by the interaction with short laser pulses.



◀ (a) Photoelectron spectrum for the ground *g* state for three orientations β of the polarisation vector with respect to the molecular axis for femtosecond laser ionization. Shaded areas show the *g* and *u* decomposition of the total spectrum. The inserts represent the PAD for a perpendicular geometry at energies indicated. All are normalized to 1 at the maximum of the PAD. (b) Same as (a) but for the first excited u state.

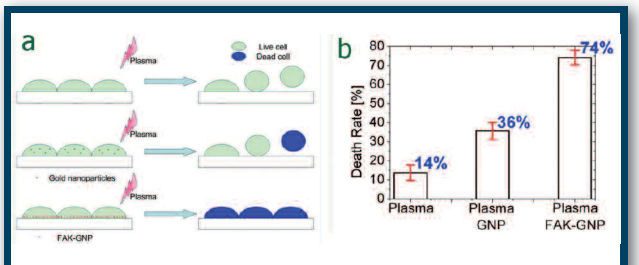
The asymmetry is apparent in the photoelectron angular distribution (PAD) of the ground *g* and first excited *u* state. The PAD presents a forward-backward asymmetry that strongly depends on the final electron energy (see figure). This loss of inversion symmetry results from the entanglement of continuum states with *g* and *u* symmetry – the strict *g* or *u* symmetry is lost The results are based on a new *ab initio* approach combining grid-based and basis state calculations. A striking feature is observed in the PAD from the *u* state: the electron is prevented from escaping in the direction of the field when the molecule is perpendicular to it (see figure). The origin of this anomaly is related to the initial inversion symmetry of the molecule. These mechanisms are general for all molecules under the influence of strong and short laser pulses. ■

J. Fernández and **L.B. Madsen**, 'Energy-resolved photoelectron angular distributions of H_2^+ in intense femtosecond laser pulses', *J. Phys. B* **42**, 021001 (2009).

Antibody nanoparticles: a new weapon against cancer

In our difficult war against cancer (S.Begley, *Newsweek*, Sept. 6, 2008; B.Saporito, *Time*, Sept. 4, 2008) for the past few decades, we have emerged out with a drastically novel therapeutic approach. This uses antibody-conjugated nanoparticles with air plasma. We achieved significant enhancement of melanoma cell death over the case of plasma alone by using air plasma with gold nanoparticles (GNP) bound to anti-focal adhesion kinase (FAK) antibody. Two electrodes covered with a dielectric material were connected to each other to generate plasma. One was connected to a low frequency (22 kHz), high voltage (5 kV) sinusoidal source and the other was grounded. This setup operates in ambient air. G361 human melanoma skin cancer cells were placed 2 mm from the plasma source for 40 s. We used 30 nm GNPs and antibody conjugation to selectively enhance its therapeutic effects. The antibody-conjugated gold nanoparticles (FAK-GNPs) are expected to be not only more lethal but also more selective against G361 cells. Three cell groups were prepared: 1) cultured in only media; 2) cultured in media containing GNPs; and 3) cultured in media containing antibody-conjugated nanoparticles. When the three groups were irradiated by plasma, the cell death rates were 14%, 36% and 74% respectively (Fig.). Our study demonstrates that the antibody-conjugated nanoparticles bind to FAK proteins specifically, irradiation of non-plasma stimulated gold nanoparticles caused deactivation of FAK, thereby increasing the death rate five times. So we can achieve a precise attack against cancer cells using plasma and functionalized conjugates made of GNPs and cancer specific antibodies. This research opens to a new paradigm where non-thermal plasma and antibody conjugated-GNPs team up to create a powerful weapon against cancer. ■

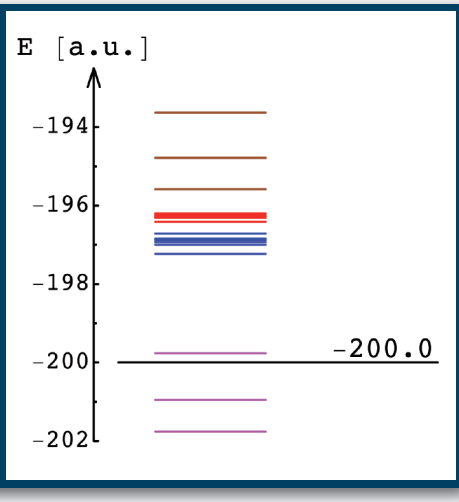
G.C. Kim, **G.J. Kim**, **S.R. Park**, **S.M. Jeon**, **H.J. Seo**, **F. Iza** and **J.K. Lee**, 'Air plasma coupled with antibody-conjugated nanoparticles: a new weapon against cancer', *J. Phys. D: Appl. Phys.* **42**, 032005 (2009)



▲ Contribution of FAK-GNPs to dramatic G361 cell death with plasma irradiation. a, Plasma-induced cell death. b, Comparison of cell death rates.

Capture of antiprotons by **highly charged H-like ions**

Since its discovery, antimatter fascinates people. Over the years, it gained increasing importance in several areas of physics and today it is linked to many fundamental questions, like symmetry and nature of the fundamental forces. However, experiments with antimatter are challenging: antiparticles annihilate very quickly when brought in contact with ordinary matter. One of only a few systems in which fast annihilation can be avoided is exotic atoms where matter and antimatter co-exist. Such systems are formed when antiprotons are trapped in long lived orbits around a nucleus, providing a natural laboratory for antimatter research. The extraordinary features of these so called "metastable antiprotonic states"



▶ Energy positions (in atomic units) of the antiprotonic resonant states in the Ca^{19+} ion in the vicinity of its ground state threshold (-200 a.u.).

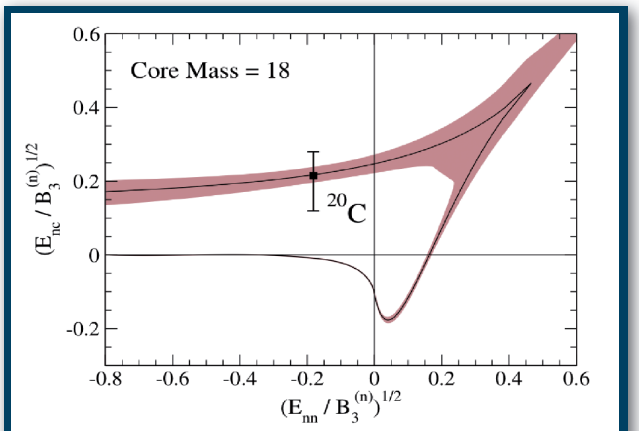
have been demonstrated in numerous experiments. New experimental facilities are now under construction, enabling production of antiprotonic systems in novel ways. In the present paper we focus on a new mechanism to produce antiprotonic atoms. It would allow for better control over the capture process and might be feasible with the upcoming facilities. The idea is to use a resonant two-step process in collisions of slow antiprotons with ions. In the first step, the antiproton is captured into an orbit around the ion nucleus, and simultaneously one of the electrons in the ion is excited. Thus, a resonant state is formed. In the second step, the electron jumps back to a low-lying state and emits a photon, hereby completing antiprotonic capture. Studying this process in medium heavy ions, we found that, once the resonant state is formed, photon emission is very likely. The estimated cross sections suggest that an experimental observation of this exotic resonant process should not be out of reach. ■

M. Genkin and **E. Lindroth**,
'Possibility of resonant capture of antiprotons by highly charged hydrogen-like ions', *Eur. Phys. J. D* **51**, 205 (2009)

Universal properties and structure of halo nuclei

There has been renewed interest in quantum many-body systems with large scattering length a recently, largely because in ultracold atomic gases a can be tuned to arbitrary values via Feshbach resonances. In the so-called 'unitary limit' of infinite scattering length such systems exhibit universal properties, independent of the microphysics. Since the neutron-neutron scattering length is large compared to the range r_0 of the nucleon-nucleon interaction, the question arises whether such universal properties can also be observed in nuclei. Of particular interest is the question of 'Efimov states' in the three-body system, which arise if at least two of the three pairs of particles have a large scattering length compared to interaction range. The number of the ensuing three-body bound states, which are geometrically spaced between h/mr_0^2 and h/ma^2 grows to infinity as a diverges. Treating neutron-rich light nuclei ('halo nuclei') as an effective three-body problem with a core and two valence neutrons, the possible existence of Efimov states is addressed by using an effective field theory approach. To leading order in a (r_0/a) – expansion, the Faddeev equations for the core and the two halo neutrons are solved and next-to-leading order corrections are estimated as systematic errors. As a function of the two-body bound (virtual) state energies of the neutron-core (E_{nc}) and the neutron-neutron (E_{nn}) systems the boundary of the region with at least one excited Efimov state is calculated and an error band provided. It is found that none of the known halo nuclei is likely to have an excited Efimov state, with the possible exception of ^{20}C. ■

D.L. Canham and **H.W. Hammer**,
'Universal properties and structure of halo nuclei', *Eur. Phys. J. A* **37**, 367 (2008)



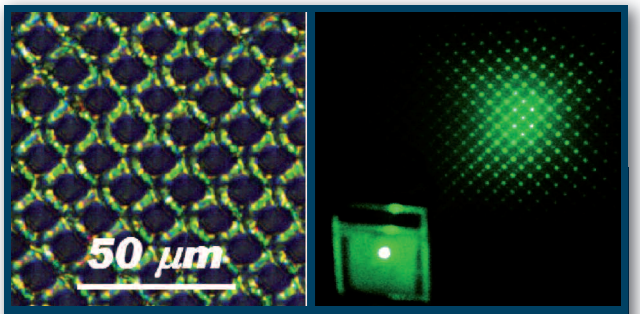
▲ Boundary region in the E_{nc} vs. E_{nn} plane where the first excited Efimov state $B_3^{(n+1)}$ is exactly at threshold. Negative values on the axes correspond to virtual (unbound) two-body states. The shaded band indicates the error estimate from next-to-leading order corrections.

Photonic lattices in polymer-liquid crystal composites

Recent efforts in the development of new photonic bandgap materials are focusing on tunable structures that permit to change optical properties continuously and reversibly. Liquid crystalline (LC) materials ideally suit for this purpose. Being well known for their extremely large electrooptic response utilized in various LCD devices, they provide a number of outstanding features for the fabrication of tunable photonic bandgap structures. Composites with remarkable properties can be achieved by incorporating liquid crystals into photopolymer networks by means of holographic lithography technique, which represents a fast and relatively simple way for fabrication of 1D, 2D and 3D photonic crystals.

We performed a comparative study of the electric field-induced and temperature-induced modifications of the liquid crystal structure in a 2D square photonic lattice made of a holographic polymer-dispersed liquid crystal (HPDLC). Optical diffraction experiments combined with optical polarization microscopy indicate a multidomain orientational profile, which is gradually transformed to a homogeneous structure when the sample is exposed to an increasing external voltage or heating to the isotropic phase. The observations signify that the degree of liquid crystal ordering at the interface with the polymer-rich regions is considerably lower than in the central regions of the LC-rich domains. Our investigations represent a first step towards extensive crystallography-like characterization of the unit cell structure in HPDLC lattices. ■

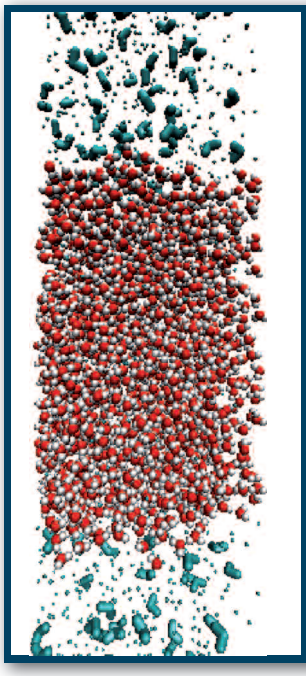
M. Devetak, **J. Milavec**, **R.A. Rupp**, **B. Yao** and **I. Drevenšek-Olenik**,
'Two-dimensional photonic lattices in polymer-dispersed liquid crystal composites', *J. Opt. A: Pure Appl. Opt.* **11**, 024020 (2009)



▲ Polarization optical microscopy image of the square HPDLC lattice under crossed polarizers. Structured areas are liquid crystal-rich regions and dark areas are polymer-rich regions (left part of figure). Far field optical diffraction pattern of the lattice observed with the laser beam at 532 nm (right part of figure).

A molecular dynamic study of **water/methane/propane**

We present a molecular dynamic simulation for water/methane/propane. The simulation is performed in a constant *NPT* ensemble at a temperature of 240 K and a pressure of 300 bar. The simulation is analysed to calculate the propensity for hydrogen bond formation, potential energy, number density profile and radial distribution function. Compared with the binary system (water/methane), relatively slight changes in hydrogen bond number and potential energy for the ternary system (water/methane/propane) indicate that the presence of propane retards the rate of hydrate growth.



◄ Snapshot of the simulation cell. A film of water, with dissolved methane and propane, is surrounded by a methane and propane fluid. Water molecules are in the central region; methane molecules are depicted by the smaller spheres, and propane molecules are represented by the thick cylinders.

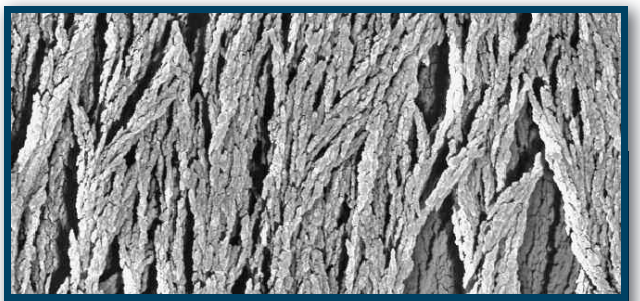
It is interesting to observe that propane, which is also of hydrophobic nature as methane, does not promote the formation of hydrate, but is rather driven out of the middle aqueous region. No hydrate formation was observed even after all of the propane had been driven out of the water film. We suggest that the size of water clusters and hydrogen bond network is likely to be disrupted by propane molecules, hindering the growth of the nuclei to the critical size required for sustained growth. The presence of the propane might also affect the net flux of methane into the aqueous phase, which is critical for hydrate formation. Our research offers insight into the nucleation theory. ■

Junfang Zhang, **Yong Guo**, **Ye Yang** and **K. Kozielski**,
'A molecular dynamic study of water/methane/propane',
J. Phys. B: At. Mol. Opt. Phys. **42**, 035302 (2009)

Electro-optics of ferroelectric liquid crystals

Polymer-stabilised liquid crystals (PSLC's) consist of a relatively low concentration of photo-polymerised monomer which is phase-separated from a continuous liquid crystal medium. Prior to polymerisation the monomer aligns itself with the self-organising liquid crystalline host. During the polymerisation process the monomer forms a network in the general direction of the liquid crystalline host, in effect templating the order of this host in which it was formed. This templating effect has been demonstrated for different types of liquid crystals, including nematic ones, to the more complex ferroelectric ones. In fact intricate helical structures can be formed if the network is formed in a helical liquid crystal. PSLC's retain the useful electro-optic properties of common liquid crystals but possess higher mechanical stabilities and gain unique further abilities and functionalities. They have a wide-ranging application potential, with uses as diverse as privacy windows, reflective display devices, heat repelling sheets and optic devices in switchable photonics and dynamic holography. To gain an insight into the effects of a stabilising, phase-separated polymer network on the electro-optic performance of a polymer stabilised ferroelectric liquid crystal (PSFLC), several investigations were performed on key material properties prior to, during and after photo-polymerisation. The investigation provided evidence for how this polymerisation process is accomplished and why the favourable electro-optic properties of ferroelectric liquid crystals are retained in PSFLCs. Possible explanations for the behaviour of different electrooptic effects were discussed in terms of phase behaviour, viscosity changes during polymerisation, polymer network phase separation from the liquid crystal and elastic interactions between network and liquid crystal. ■

P. Archer and **I. Dierking**,
'Electro-optic properties of polymer-stabilized ferroelectric liquid crystals before, during and after photo-polymerisation',
J. Opt. A: Pure Appl. Opt. **11**, 024022 (2009)

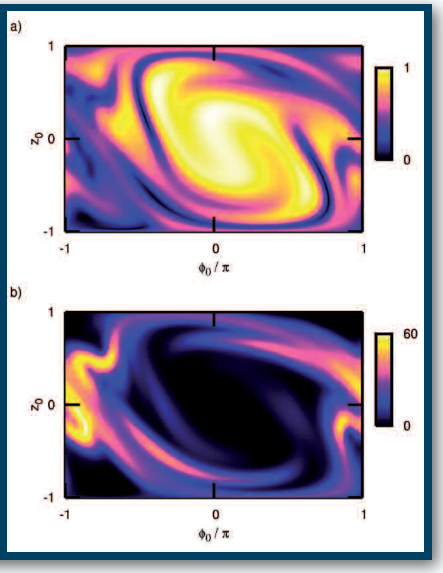


▲ Scanning electron microscope image of a polymer network formed in the Smectic A* phase of a ferroelectric liquid crystal.

Signatures of chaos-induced **mesoscopic entanglement**

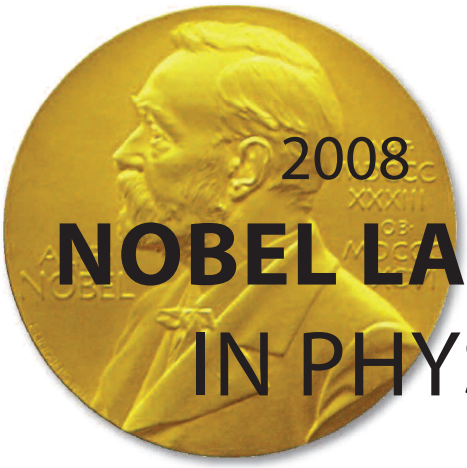
Entangled states are highly interesting from a fundamental point of view, because they are as far as possible away from classical physics. In current experiments researchers attempt to create entangled states not only with a small number of particles like in the EPR-Paradox, but also in mesoscopic systems. Bose-Einstein condensates (BECs) promise to be excellent candidates for such systems, although the realization of mesoscopic entangled states and their measurement is still under active discussion. We numerically investigated how to get signatures for chaos-induced entanglement in a system of a BEC in a double well potential.

The analysis consists of two parts: First the variance of the population imbalance between the two wells is calculated, which is experimentally easily accessible. For pure states this is equivalent to the Quantum-Fisher Information (QFI) – a flag for entanglement. Another indication for entanglement is provided by interference patterns. We numerically showed that certain chaos-induced mesoscopic superpositions have the property not to show interference fringes. However, also heating could be the reason for such disappearance of interference fringes. Hence, the reappearance of an interference pattern after a short time gives a strong indication that the system was in an entangled state. Since experiments usually are performed many times, the simulations also cover small parameter variations, which certainly would occur in an experiment. ■



▶ For all initial conditions of the system characterized by the population imbalance z_0 and a phase between the two condensate parts φ_0 (a) the visibility of the interference pattern and (b) the Quantum-Fisher Information (QFI) after time τ are displayed. Where highly entangled states appear (*i.e.* high QFI) the visibility is relatively low.

C. Weiss and **N. Teichmann**,
'Signatures of chaos-induced mesoscopic entanglement',
J. Phys. B: At. Mol. Opt. Phys. **42**, 031001 (2009)



2008 NOBEL LAUREATES IN PHYSICS

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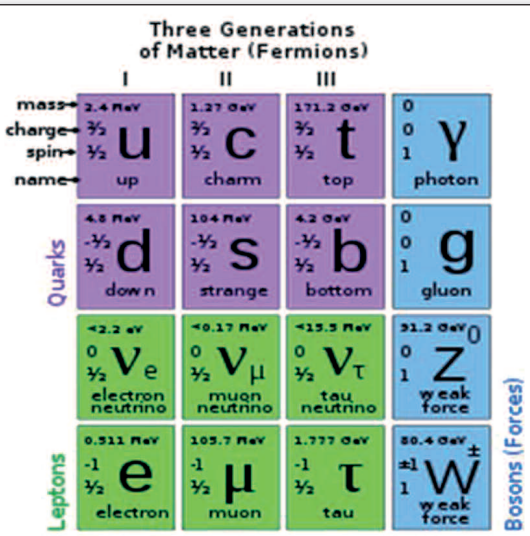
DOI: 10.1051/epn/2009401

CONGRATULATIONS NAMBU SENSEI, MASKAWA SAN, KOBAYASHI SAN!

We have been waiting for a long time for this festive occasion. For Nambu Sensei, it should have happened many years ago, for many reasons. For Maskawa San and Kobayashi San, it could have happened anytime after the 2001 discovery of the large CP violation in B decays by Belle and Babar.

Finally it happened! First, I will discuss my personal contacts with the three Nobel Laureates. Next, I will discuss spontaneous symmetry breaking in connection with the standard model, on which the Kobayashi-Maskawa theory is based. Then I will discuss CP symmetry and what I know about how the theory was discovered. Finally, I will very briefly discuss how the prediction of the KM theory, the large **CP** violation in *B* decays, was verified. Of course Nambu Sensei's discoveries spans through the entirety of particle physics. Here, I have to restrict myself to those topics, which played crucial roles in the discovery of the KM theory. It took 35 years and funding of all together 700 million US$ to build asymmetric e^+e^- colliders at KEK and SLAC to discover the large **CP** violation. Thus the experimental aspect is a story in itself. Unfortunately, I will not be able to do justice in covering this fascinating tale.



▲ **FIG. 1:** In today's standard model (SM), there are 3 generations of quarks and leptons, and a set of gauge bosons *W*, *Z* and a photon. The figure is obtained from Wikipedia

Introduction

How could I address Professor Nambu as anything but "Sensei", which means teacher in Japanese. When I was in High School, I lived with my parents in the suburb of Chicago. A bit more than 47 years ago, I visited his office at University of Chicago to talk to him about the possibility of becoming a physicist. Sensei gently explained various aspects of doing research to this kid who just happened to drop in.

Later on, as a graduate student, I remember that I was deeply moved when I studied many of Sensei's works. Then I often met him at Fermilab, where I too have been working, and he was a frequent visitor. He explained his ideas to us young physicists in a fatherly manner. One night, I saw him in a parking lot at Fermilab. He showed me the stars through a telescope, which he placed on the roof of his car.

Nambu Sensei's Nobel Prize citation reads: "for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics". He brought in the concept of spontaneous broken symmetry, which was used to explain many solid state phenomena, into fully relativistic field theory.

Introduction of spontaneous symmetry breaking into a gauge theory was a crucial step towards formulating the theory of electroweak interaction - which is the foundation of Kobayashi-Maskawa (KM) theory. The KM theory has its root in E-ken[1] of Nagoya University, where I worked from 1992 to 2006. The laboratory was set up by late Sakata Sensei. At E-ken all researchers were treated equal. This even included graduate students. So, everybody was addressed "San" which is equivalent to "Mr" or "Ms". As students, Kobayashi San and Maskawa San were nurtured by the E-ken atmosphere, which led to their discovery:

1. They truly believed in the existence of quarks- as did everybody at E-ken where the Sakata Model was born. This

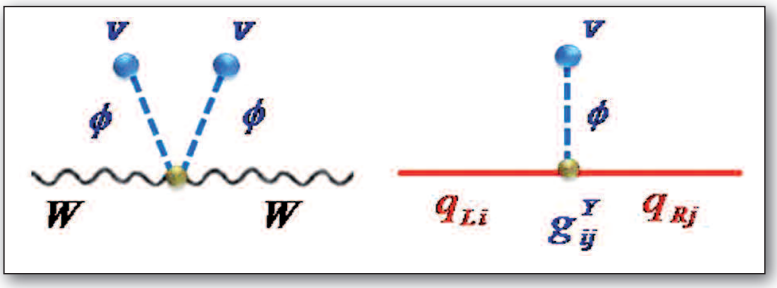
is not so for the inventor of the quark model, Gell-Mann. He stated, in his book Eightfold Way[1], that quarks are mathematical objects to be thrown out after calculation.

2. There were many field theory experts at E-ken. Ohnuki San was stressing the importance of freedom in rotating phases of fields. Remember that, in principle, the electric charge can be complex. For example, in classical electromagnetism, the forces on a particle with charge e is given by $\vec{F} = e\vec{E}$ and $\vec{F} = e(\vec{v} \times \vec{B})$. So the phases of $\vec{E}$ and $\vec{B}$ can be adjusted to define e to be real. Also, in quantum mechanics, the probability of observing a collision, $A+B \rightarrow C+D$, is given by $|\langle C+D|H|A+B\rangle|^2$. So, phases of $A \ldots D$ can be changed without affecting observables.
3. Their experimental colleague, Niu San had emulsion pictures of particle tracks corresponding to a particle with the mass of about 2GeV, and the lifetime consistent with a weakly decaying object.

While there were only 3 known quarks at that time, Kobayashi San and Maskawa San were convinced that 4 quarks existed: u, d, s and c shown in Fig. 1. They also knew that phases of quarks can be rotated so that certain coupling constants can be defined real.

Spontaneously broken symmetry

To break a symmetry of a theory we are used to adding a symmetry breaking term to a Lagrangian. There is another way. A Lagrangian respects the symmetry. But it may have large number of degenerate ground states consistent with the symmetry. The system chooses one of them. Thus the symmetry is broken. A simple example is the motion of a ball in a roulette wheel. It has rotation symmetry. When the ball settles into a particular number, the rotation symmetry is lost. We start out with a theory with $SU(2)\times U(1)$ symmetry. In this theory, weak bosons and quarks are massless. For this reason, the theory is renormalizable. But, for the same reason, it has nothing to do with the real world, where quarks, leptons and gauge bosons have masses. Weak bosons can be made massive by adding mass terms to the Lagrangian. But then, $SU(2)\times U(1)$ symmetry is broken and quantum corrections involving weak bosons become divergent - the theory becomes unrenormalizable. Weinberg suggested that $SU(2)\times U(1)$ symmetry is broken spontaneously. In this case the ground state is such that the Higgs boson acquires a vacuum expectation value v. That is, the ground state is filled with something analogous to "ether". Particles get masses through the interaction with ether. This is depicted in Fig.2. Then, weak bosons become massive and yet, like magic, there is enough symmetry left in the theory so that most of the infinities cancel - theory becomes renormalizable.



▲ **FIG. 2:** Through the interaction of Higgs particle, W bosons and quarks become massive. Here q_i stands for any one of (u, c, t) or (d, s, b) quarks. Of course, since ϕ is neutral, they must have same charge. The subscript L and R stand for left and right helicities, respectively. If $i \neq j$, the Higgs interaction changes a quark of one generation to another. The interaction is caused by a Yukawa coupling with coupling constant g^Y_{ij}.

CP symmetry

Quantum mechanics must be formulated in terms of complex numbers, as seen by its most important relation: $[x, p] = i\hbar$. Now, in quantum field theory, if there is an operator Ψ, because it is a complex operator, there is another operator $\Psi^\dagger$. It can be shown that, if Ψ creates a particle with charge e, $\Psi^\dagger$ creates a particle with charge $-e$ but exactly of the same mass. So, quantum field theory requires that, for each particle, there exist an antiparticle. The operator **C** changes particles to their corresponding antiparticles.

The parity operator **P** transforms position $\vec{r}$ to $-\vec{r}$. The discovery of parity violation gave a big shock to many physicists at that time. But they were relieved that combined symmetry CP remained conserved.

Their relief was short lived, however. In 1964 Cronin and Fitch discovered **CP** violation in K decays[2]. It was a tiny breaking, 0.2% - nevertheless, it gave another big shock.

It is easy to see that **CP** violation is caused by phases in the theory. Consider a term in the Hamiltonian h, which causes an interaction of particles. Then it can be seen that $h^\dagger$ causes an interaction of corresponding antiparticle, and $\mathbf{CP}h\mathbf{CP}^\dagger = h^\dagger$. Since the total Hamiltonian must be hermitian, these interactions must be introduced as:

$$H_{int} = ch + c^* h^\dagger, \qquad (1)$$

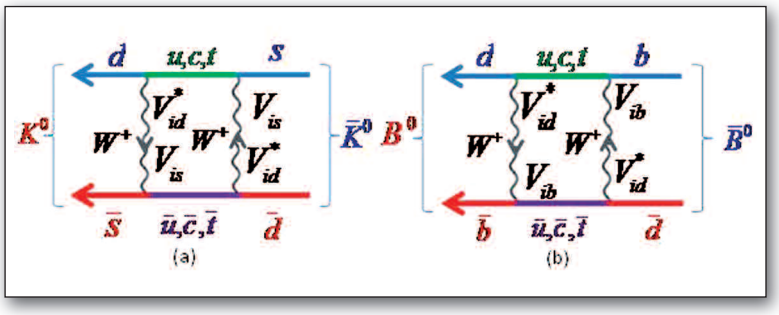
where c is a constant. Note that if c is real, H_{int} is invariant under CP transformation, *i.e.* $\mathbf{CP}H_{int}\mathbf{CP}^\dagger = H_{int}$. So, physics of **CP** violation is physics of phases.

The road to KM theory

As Kobayashi San was leaving for Kyoto University, he gave an introductory seminar on Glashow-Salam-Weinberg theory of electroweak interaction. At the end of the seminar, I hear that Ohnuki San asked the question *"How does one understand **CP** violation in this formalism?"* I think this was the question that triggered the investigation by Kobayashi San and Maskawa San.

Let us assume that there are 3 generations of massless quarks and denote them by a superscript "0". Weak interactions are given by:

$$L_{int} = ig(\bar{u}^0 \ \bar{c}^0 \ \bar{t}^0) \ L\gamma\mu \ \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} d^0 \\ s^0 \\ b^0 \end{pmatrix} \ W^\mu, \qquad (2)$$



▲ **FIG. 3:** A diagram responsible for CP violation in K and *B* decays.

where g is the gauge coupling. Note that it does not change quark generations. We must however, derive the W boson interaction with real particles with masses. As described in Fig.2, quarks with same charge get totally mixed through interactions with the "ether". When L_{int} is written in terms of the mass eigenstates, it becomes:

$$L_{int} = ig(\bar{u}\ \bar{c}\ \bar{t})\ L\gamma\mu \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} W^{\mu}, \quad (3)$$

where **V** is a unitary flavour mixing matrix. The mixing matrix **V** contains phases coming from complex Yukawa couplings g^{Y}_{ij} shown in Fig.2. Note that when L_{int} is written in terms of mass eigenstates, it causes transition of a quark of one "flavour" to another. Let us assume that there are only two generations (u, d) and (c, s). Then unitary 2×2 matrix **V** has 4 parameters. Using the phase freedom of 4 quarks, discussed in Sec. 1, all elements of **V** can be made real. Thus **V** becomes an orthogonal matrix with one parameter: the Cabibbo angle.

Thus they came to the conclusion that, with 2 generations, **CP** cannot be violated. Then according to Maskawa San, he suddenly had a thought while he was taking a bath. Rather than writing a paper with the negative conclusion, let's assume 3 generations of quarks. Then there are 9 parameters in **V**, and 6 quark phases that can be adjusted. They have shown that there remains 1 phase which can not be removed by any phase redefinition. This theory contains **CP** violation.

Confronting experiments

Now the big question is, "Does the KM theory have anything to do with the real world?" Indeed, over many years, members of the 3rd generation have been discovered. But, the crucial test is to find **CP** violation in *B* decays.

Fig.3 shows one of the most exciting quantum mechanical phenomenon. By exchanging 2 *W* bosons, a K^0 meson can transform itself into its antiparticle $\overline{K}^0$ and vice versa. The amplitude for this transition is written as $M_{K\bar{K}}$. The state K^0 will oscillate between K^0 and $\overline{K}^0$ before it decays. It goes through intermediate states which may be any combination of (u, c, t), and $(\bar{u}\ \bar{c}\ \bar{t})$. In particular, an amplitude which contains t or $\bar{t}$ quark intermediate state is proportional to $V_{ts}V^{*}_{td}$ which is complex, *i.e.* it will cause **CP** violation. Theoretical analyses show K^0 meson **CP** violation is observed in decays, which depend on this oscillation.

Now, if we replace the *s* quark with *b* quark, we have Fig.3(b). It predicts B^0 - $\overline{B}^0$ oscillation[4]. There will be **CP** violation in B^0 decay if $V_{tb}V^{*}_{td}$ has a phase. But, the lifetime of the *B* meson is only about 1.5ps - even light travels only about 0.45mm during this time. So, unless there is large **CP** violation, and lots of luck, it is impossible to see the effect. Now the crucial question is: "Could the values of the mixing matrix be such that $M_{K\bar{K}}$ is almost real, so that *K* meson **CP** violation is only 0.2%, and yet $M_{B\bar{B}}$ has a large phase?" I. Bigi, A. Carter and I investigated this possibility. In 1980, we have made a prediction of possible large **CP** violation in B decay, and it was verified in 2001 by Belle and BaBar. It should be mentioned that an asymmetric e^+e^- collider, with the luminosity 1000 times higher than the maximum available at that time, had to be built. Also a detector having the height of a three story building, and the spatial resolution of microns with excellent particle identification had to accompany the collider. Since B's are pair produced in $e^+e^- \rightarrow B^0\overline{B}^0$, one of them had to be tagged for particle identification. Then the search for the other to decay to $J/\psi K_S$ begins. It takes full use of EPR correlation. Looking back after 28 years, we now know that, out of all possible values for V_{ij}, Nature chose exactly that small region where there is almost 100% **CP** violation in *B* decays, and only 0.2% for *K* decays. The way Nature has chosen exactly this value that we needed, I am convinced, is not by accident. It seems like there is a law that states symmetries are broken in the largest possible way.

Remarks

KM theory states that CP violation is a natural consequence of the SM - which in general has complex Yukawa couplings. It is very elegant. On the second thought, how could the theory this elegant be so ugly? It has 18 complex Yukawa couplings which must be introduced by hand. Surely this is not the end of the story. These Yukawa couplings must be a natural consequence of a more fundamental theory. Solving this mystery will probably lead to the understanding of **CP** violation which causes the baryon asymmetry of the Universe. The real treasure is not yet discovered! ■

notes

[1] "E" stands for Elementary Particle, and "ken" stands for laboratory.

[2] K^0 is made out of $\bar{s}d$, where $\bar{s}$ stands for anti-*s* quark.

[3] Note that the converse of above statement is not true. The complex phase will not always result in observable **CP** violation, as it is shown below.

[4] B^0 meson is made out of $d\bar{b}$ quarks.

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A PHYSICAL PALETTE FOR ION-BEAM CANCER THERAPY

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For more than ten years, ion-beam cancer therapy has been successfully used clinically in Germany and Japan. Proton-beam therapy is performed in many more centres around the globe. Thousands of patients per year are being treated. These therapies appear to be a more favourable alternative to the conventional photon therapy, also known as radiotherapy [1]. Despite apparent experimental and clinical successes, a comprehensive theoretical description of a physical scenario is missing.

One reason is that phenomena initiated by an energetic ion incident on tissue happen on many scales in time, distance, and energy. Many thorough papers have been devoted to Monte Carlo simulations of different fragments of the scenario, but they cannot include all scales together because, *e.g.*, time scales for physical processes vary from 10^{-22} s to 1 s. In addition, they do not present the scenario as a hierarchy of phenomena, which is very attractive physically. Our goal is to understand the physics of beam therapy on a microscopic level and, while moving towards this goal, we present a multi-scale approach to the scenario of irradiation with ions.

▲ P.21: Man Receiving Electron Radiation Therapy for Skin Cancer over the Eye. ©istockphoto

DNA is disrupted as a result of energy deposition by incident ions, mainly due to ionization of the medium. The secondary electrons formed in this process are considered to be mostly responsible for DNA damage through either direct breaking of DNA strands, or reacting with water molecules producing more active secondaries, or through heating of the medium. In Fig. 1, we depict the schematics of the multi-scale scenario. In our approach, we go through the major phenomena involved in this scenario on different scales.

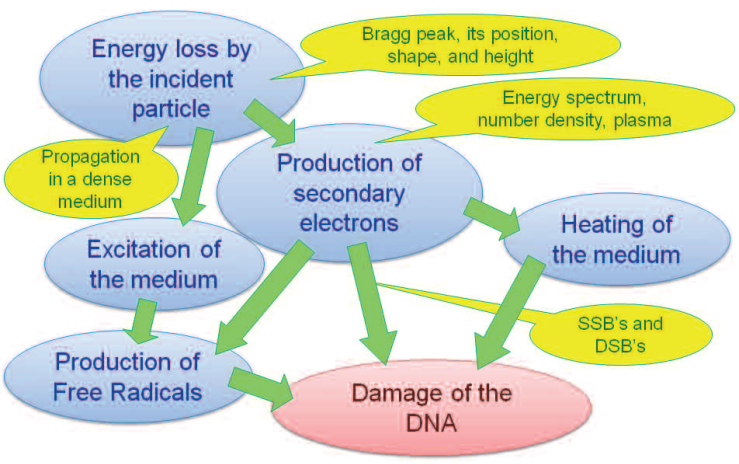
Ion stopping and production of secondary electrons

The advantages of hadron beam therapies are centred on the fundamental difference in energy deposition profile between a massive projectile and a massless photon. The key feature is the Bragg peak: a sharp maximum in the linear energy transfer (LET) of the projectile (see Fig. 2 for an example). This peak results from the fact that the inelastic cross sections sharply increase as the speed of the projectile decreases. It is due to this peak, that the effect of the irradiation on the tissue can be more localized, increasing the efficiency of treatment and reducing side effects.

Position and shape of the Bragg peak are defined by the type of projectile, its initial energy, and properties of the medium. Using information about the cross sections of atomic and nuclear processes as inputs, Monte Carlo simulations [2] predict all characteristics of the Bragg peak. However, their ultimate output is not sufficient since the energy steps are much larger than needed to resolve the microscopic scale.

We have used as an input the singly differentiated cross section (SDCS) of ionization of water molecules (water has been a substitute for the biological tissue) [3,4] and obtained the position of the Bragg peak with a less than 3% discrepancy from both simulations and experiments [3]. In order to achieve this, we corrected a semi-empirical parameterisation of SDCS for relativistic velocities of projectiles and included energy losses due to excitation of the medium. The shape of the Bragg peak is influenced by effects of charge transfer due to picking-off electrons by the initially fully stripped ions (such as $^{12}C^{6+}$) as they slow down, and by projectile scattering. These were included by introducing an effective charge of the projectile and energy straggling (energy spreading due to ion scattering). The resulting shape of our Bragg peak matches the simulated shape if nuclear fragmentation is ignored [3]. Nuclear fragmentation, in the case of carbon ions, is quite substantial and should not be neglected, but so far we have left it for future work. Our calculations [3] are shown in comparison with simulations (ignoring nuclear fragmentation) in Fig. 2.

The SDCS of the energy loss by ions in liquid water taking into account relativistic effects is the cornerstone of ion stopping, the energy spectrum of the secondary electrons, and the production of radicals via excitation of water molecules. The effects represented by the SDCS both define the longest scale related to the ion propagation and provide the initial conditions for the next scale related to the secondaries.



▲ **FIG. 1:** Schematics of the multi-scale approach.

Propagation of secondary electrons and DNA damage

The next scale is defined by secondary electrons. These are produced by ionization of molecules of the medium and by radicals formed as a result of energy loss by the projectile. The maximum energy on this scale hardly exceeds 100 eV and the displacement is of the order of 10-15 nm. The main activity of this scale is diffusion of free electrons and radicals in the medium. Many chemical reactions take place as well; they are also important for estimates of the DNA damage since they

define the agents interacting with the DNA. Again, this aspect has attracted plenty of attention of Monte Carlo simulations adepts [5] who, using various SDCS of ionization (including the effects of the medium [6-9]), trace the electrons and other species through the medium up to their interaction with the DNA. We developed an approach to calculations that can be done on this scale without using Monte Carlo simulations [10,11].

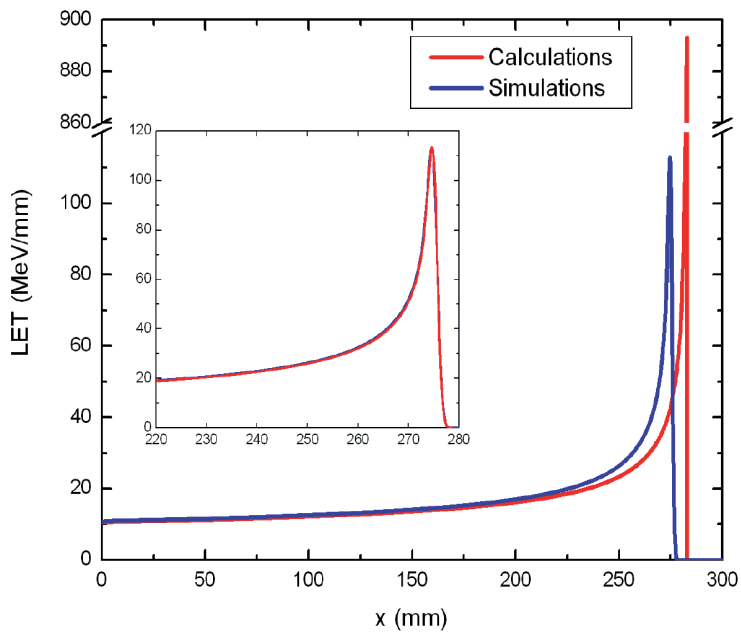
DNA damage, such as a Single Strand Break (SSB), is a result of a sequence of mutually independent events, such as the production of secondary electrons, their diffusion, and the interaction of incident electrons with DNA. We use the energy spectrum of secondary electrons obtained in Ref. [3] and describe their propagation through the medium using a random walk approximation. This is justified since their angular distribution is flat to a first approximation [5]. We also use mean free paths of electrons taken from Ref. [8] and obtain the number of electrons crossing the surface of a cylinder, which represent a single convolution of a DNA molecule. This number multiplied by the probability of a SSB gives the number of SSB's per DNA convolution per ion. The probability of a SSB is taken from experimental data [12], since a complete analysis should include a quantum mechanical treatment of the electron interaction with DNA, which is not feasible at this point. The complete description of this procedure is in Refs. [10,11], and we present some results of this analysis here.

From the most general geometrical configuration presented in Fig. 3 we selected two limiting cases: the DNA convolution being parallel or perpendicular to the ion track. In Fig. 4a, we compare the numbers of SSB's due to the total number of cylinder surface crossings. The difference between the curves is not very significant and all curves due to other possible geometrical situations lie in the shaded area between the curves in this figure. We infer that the geometrical differences are not so important for the final result and that geometrical details of the orientation of DNA segments with respect to the beam may not be so significant.

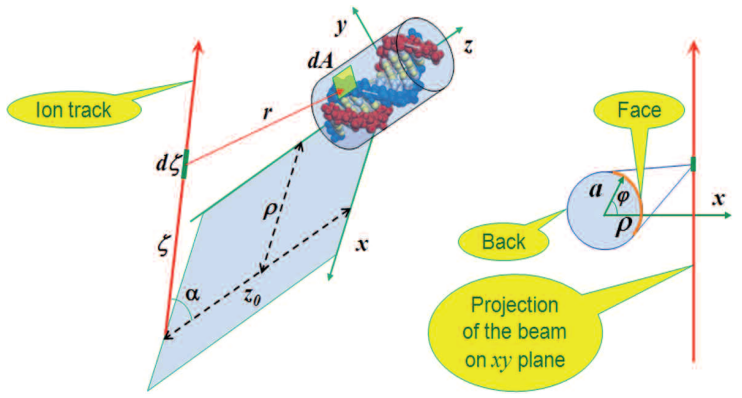
Calculation of the number of Double Strand Breaks (DSB) is more important, since clustered DSB's are irreparable damage. In order to do this calculation, we notice that the measured dependence in Ref. [12] is principally different for more energetic (>5 eV) electrons, for which the probability of a DSB per electron is proportional to the probability of a SSB per electron. This means that most of DSB's are produced by the same electrons or, if an electron breaks a strand, it is much more likely to break another one as well. For less energetic electrons this is unlikely, so the probability of a DSB is proportional to the *square* of the probability of a SSB. This means that the DSB's are produced by different electrons. However, the electron densities used in the experiments of Ref. [12] are about 10^{16} times smaller than those caused by ions in the vicinity of the Bragg peak [3,4]. Therefore we should consider both cases since they may both be important. The results for the DSB's caused by the same electron would be roughly equal to the number of SSB's shown in Fig. 4a divided by a factor of 5. The probabilities of DSB's due to different electrons are shown in Fig. 4b, again for parallel and normal cases. Once again we see that the dependence on geometry may not be so important. Secondaries such as next-generation electrons produced by secondary electrons and free radicals produced by ions after excitation or ionization of the medium can be treated in a similar way.

Having calculated the probability of a DSB in a convolution located at a certain distance from the beam, we calculate the number of DSB's due to one ion passing through the tissue. In order to do this, we introduce a distribution of cylinders representing convolutions of DNA and sum all their contributions. For our first

▼ FIG. 2: The Bragg peak in the Linear Energy Transfer for a single ion, *i.e.*, without scattering, showing discrepancies in depth and height between the calculations and Monte Carlo simulations. In the inset, straggling (but not nuclear fragmentation) is included resulting in excellent agreement between the two.[3].



Complexity of the **geometry of DNA** in **different states** may be **overcome,** because the **geometrical differences** are **insignificant**

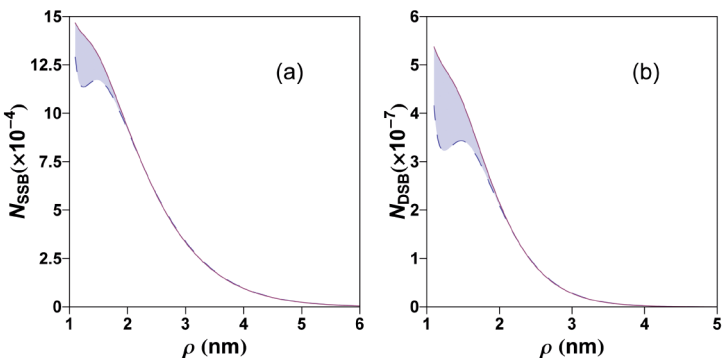


▲ **FIG. 3:** Geometry of the problem. The cylinder represents a single convolution of a DNA molecule, which may have various orientations with respect to the ion track.

estimate, we used the thoroughly studied (experimentally) glial cells, which comprise 90% of the human brain. We have assumed a uniform distribution of DNA inside the cell nuclei in their interphase and calculated that each ion in the vicinity of the Bragg peak passes through about 75 cells causing about 17 DSB's per nucleus. While it is travelling through cell nuclei, it causes 3.3 DSB/μm, comparable to the observations of Jacob *et al.*, [13].

The multi-scale inclusive approach to the physics relevant to ion-beam cancer therapy is aimed at presenting a clear physical picture of the events starting from an ion entering tissue leading to DNA damage. We view this scenario as a palette of different phenomena that happen on different time, energy, and distance scales. From this palette, we choose the major effects that adequately describe the leading scenario and then describe ways to include more details. We think that calculations in this field can be made inclusively without dwelling on a particular scale. Our calculations are time effective and can provide reasonable accuracy. They show that the seemingly insurmountable complexity of the geometry of DNA in different states may be overcome, because the geometrical differences are found to be insignificant. We would like to encourage experimentalists to provide data more relevant to the actual conditions of irradiation, especially on the smallest scales involving DNA damage. This information is vital for further tuning of our approach by selecting and elaborating on the most important aspects of the scenario.

▼ **FIG. 4:** A comparison between the numbers of Single Strand Breaks due to the whole surface of the cylinder **(a)** and Double Strand Breaks caused by separate electrons **(b)** as a function of distance to the DNA convolution in the parallel (blue) and normal (violet) cases, for 20-eV electrons.



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NUCLEI "AT THE TOP OF THEIR SHAPE"

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The atomic nucleus is an ideal laboratory not only for physicists, but especially for mathematicians. Indeed, nowadays a wide variety of theories based on quantum mechanics as well as semi-classical approaches have been applied to nuclear structure and reactions and innumerable experiments have been performed to test them. The most striking feature of the nucleus is that it continues to challenge physicists of all sorts.

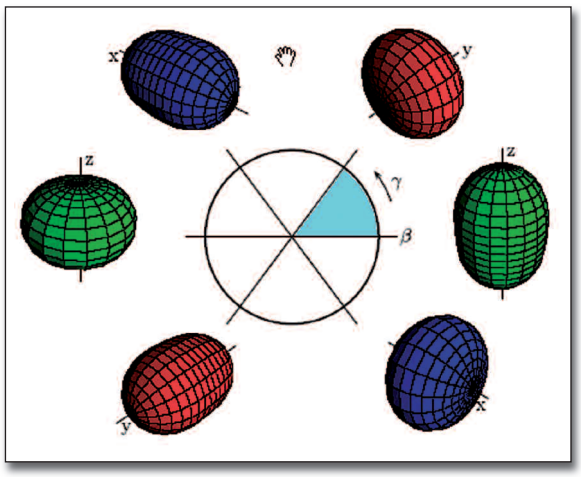
This is because it displays an everyday richer phenomenology that underlies abstract mathematical concepts, such as group theory and Lie algebras, which are used to describe "hidden" symmetries. Those symmetries, contrariwise to more commonly used ones, such as translational invariance, parity, time-reversal, or even geometric symmetries, are not properties of the object itself, but rather are contained in their quantum mechanical Hamiltonian. We will dwell, in the following, on the Bohr Hamiltonian and the newly discovered symmetries that are associated with it.

Droplets and quadrupoles

Since the beginning of nuclear physics the phenomenology of the atomic nucleus has been profitably described in terms of a droplet of a quantum liquid. This semi-empirical model, due to von Weizsäcker [1], incorporates a number of terms that comes from different physical considerations into a mass-formula. This approach was of a static nature, but the idea of a liquid was the starting point of a more elaborate quantum description that takes in the dynamics of surface oscillations of the drop.

The celebrated model of Bohr and Mottelson [2], that dates back to the fifties, describes certain properties of the nucleus in terms of its surface that, under the influence of a restoring force, is allowed to perform quadrupole (or, more generally, multipole) oscillations around an equilibrium ellipsoidal shape that can be spherical or deformed. Each shape is uniquely defined by five variables: two, β and γ, that encode the extent of quadrupole deformation and the asymmetry in the intrinsic frame of reference and three Euler angles, that govern the orientation in space of the intrinsic ellipsoid with respect to a laboratory frame. The first parameter, β, may be thought of as the radius in a suitable two-dimensional polar frame of reference, while the second, γ, is an angle that may range from 0 to 2π. Each point in this two-dimensional plane is uniquely associated with a given ellipsoidal shape in the intrinsic frame of reference. The three Euler angles that specify this orientation do not give further information on the intrinsic shape and therefore one can then confine this two-dimensional plane to a 60° wedge, because all the other wedges may be obtained by simply re-labelling the axes of the intrinsic frame (see Fig.1). The Bohr Hamiltonian, which is written in the intrinsic frame of reference as a partial differential equation in those five variables, is the quantized Hamiltonian for the

▲ Three-dimensional representation of a nucleon: quark and gluon structure of the proton. © Photothèque CNRS / CNET / Lactamme / J.-F. Colonna / URA756



▶ **FIG. 1:** Polar plane for the description of quadrupole shapes as a function of the radial variable β, the quadrupole deformation, and the angle γ, the degree of asymmetry (the so-called Hill-Wheeler cordinates). The fundamental 60° wedge (enlarged in fig. 2) is sufficient to describe all possible intrinsic ellipsoidal shapes [2,3] because any other point in the diagram can be obtained by simply re-labelling the intrinsic axes.

quadrupole oscillations of an ellipsoidal surface. It contains three kinetic terms (in β, in γ and rotational) as well as a potential term, V(β,γ). This last term, which is a function of β and γ, is particularly relevant to the present discussion, because it represents the potential associated with some sort of restoring force on the nuclear surface, that may be thought of as the response of the surface to an external stimulus. In principle this potential is not known and the original solution of Bohr and Mottelson used a γ-independent harmonic oscillator in β centered around the origin with the idea of describing the oscillations of a spherical surface [2].

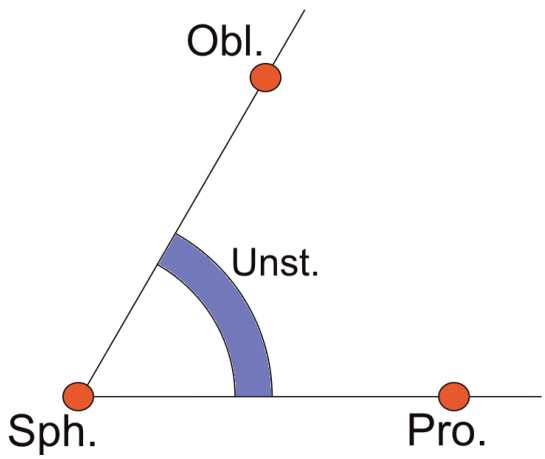
Ellipsoids

Since that successful solution a number of important analytical, approximated and numerical solutions of this Hamiltonian has been found (they are collected in Ref. [3]) and their applications to nuclear spectroscopy at low-energy have been very rewarding.

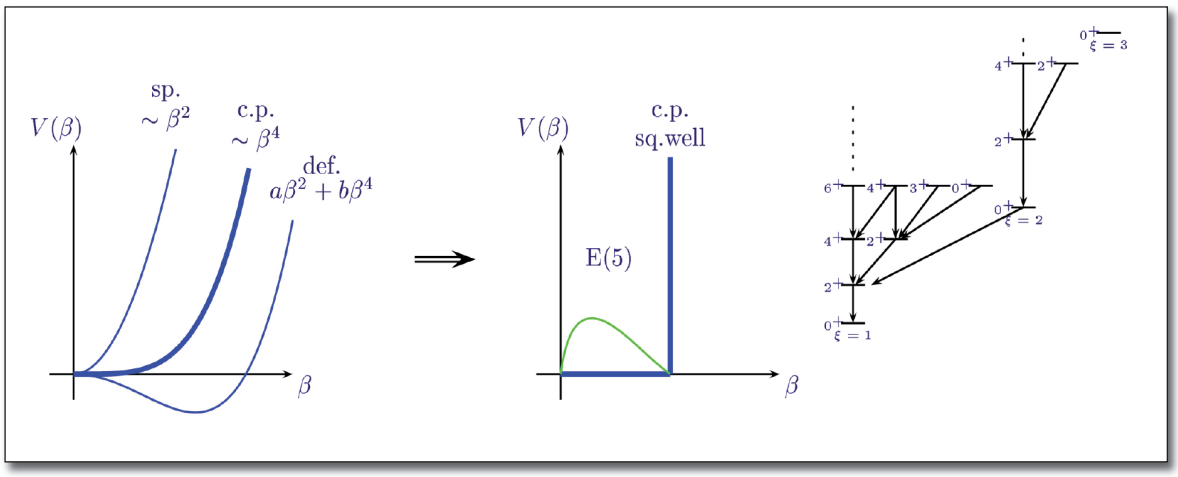
In particular three classes of solutions have been traditionally discussed which correspond to different shapes: the sphere, the prolate and oblate axially deformed ellipsoid, and the so-called γ-unstable [4]. Each of these classes comes from a potential surface with a particular position of the minima in the β-γ plane as illustrated in Fig. 2: i) when the absolute minimum is at zero the surface is spherical, ii) when it is a point with β≠0 along the γ=0 (or γ=π/3) axis the surface is a prolate (or oblate) axial ellipsoid and iii) when the locus of minima is a sort of circular valley one speaks of a γ-unstable shape [4]. In addition when the minimum is a point within the wedge, the surface is a triaxial ellipsoid. During the second half of the last century until the present time, each given shape has been the subject of many investigations which from one side have pushed the technical ability of nuclear spectroscopists (high-efficiency multi-detector arrays have made it possible to look for fine structures in spectra) and from the other have made richer our exploration of the nucleus. Just to mention a few interesting phenomena: the super- and hyper-deformation, which might occur at high spin and temperature, and their relation to fission reaction and clustering, wobbling motion, search for triaxiality and super-deformed triaxial shapes, band termination, prolate-oblate shape coexistence, octupolar and exotic shapes (See, for instance, [1,14,15,16]). Each of these topics (a few of which are well-covered in Ref.[16]) would require a separate article, but this is beyond the scope of the present paper.

Interacting Boson Model

These three classes of potential surfaces with different minima have been related to the group structures, U(5), SU(3) and SO(6) for spherical, axially deformed and γ-unstable shapes respectively. This has been possible especially after the inception of the Interacting Boson Model [1,5], a very successful algebraic approach proposed by A.Arima and F.Iachello in the mid-seventies, that parallels the collective description. In the IBM the nucleons in an even-even isotope are divided into an inert core and an even number of valence particles. These particles are then considered as coupled into two kinds of bosons (an effect essentially due to the combination of pairing and quadrupole-quadrupole interactions) that may carry either a total angular momentum 0 or 2 ,and are respectively called the s- and d-bosons. The bilinear operator that may be formed with the s- and d-boson creation and annihilation operators close into the U(6) algebra, whose three possible



▲ **FIG. 2:** On the fundamental wedge, the spherical limit correspond to the β=0 point, axially deformed prolate and oblate limits correspond to a point with non-null β and γ=0 and π/3 respectively. The γ-unstable limit corresponds to the locus of points with non-null β and 0<γ<π/3. Isolated minima in all other points (not shown) represent triaxial shapes.



◀ **FIG. 3:** The potential $V(\beta)=a\beta^2+b\beta^4$ (left) spans from spherical to γ-unstable deformed cases, crossing the critical point (c.p.). In the E(5) solution (centre) the β^4 potential at the critical point is approximated by an infinite square well. The ground state radial wave function, which is essentially a Bessel J function is shown in green. The lower portion of the analytic spectrum of the E(5) critical point symmetry is shown on the right. The slightly anharmonic eigenstates are labelled by Jπ and by a family index ξ. Arrows indicate electric quadrupole transitions.

subgroup chain match the U(5), SU(3) and SO(6) solution of the Bohr Hamiltonian. The fact that the L=2 has a privileged role in this model explains why the quadrupole degree of freedom emerges naturally from the abstract algebra. On the other hand the necessity of including L=0 monopole bosons focuses attention on the short-range pairing interaction.

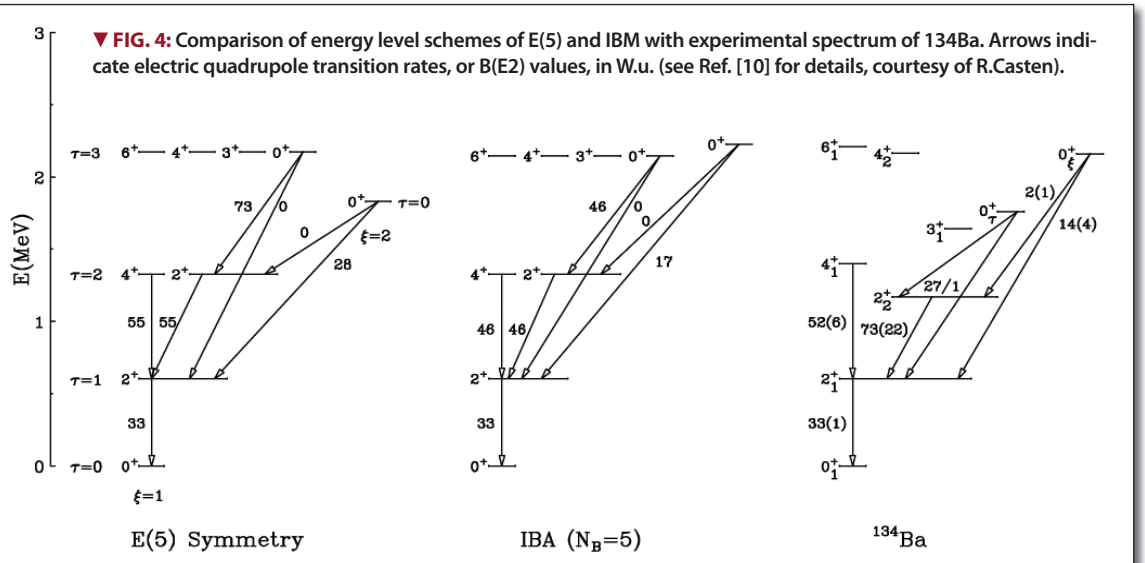
A rationale for the valence bosons ansatz is the simplicity of the model: in fact the IBM allows for treatment of heavy nuclei, where sometimes the more natural shell-model approach would need a much larger set of basis states. Although the IBM is a phenomenological model, the connection with microscopic aspects is ensured by the N-dependence across a given shell.

With the clear-cut algebraic formulation of the IBM, people have investigated its relations to the collective model and have transposed the group labels to the collective description using them as benchmarks for nuclear structure. Although a precise mapping from one model to the other is far from being trivial [17], it is clear that the collective model and the interacting boson model describe the same phenomenology with a geometrical and with an algebraic approach respectively. Roughly speaking the Bohr-Mottelson collective description can be recovered by taking the large N (boson number) limit of the IBM.

Shape-phase transitions

As has been said, a number of exact solutions of distinctive importance may be given, but alongside the three traditional ones, there are a few which have come to the fore recently because of the novelties they imply (see [3] and [13]). In fact, after one associates a certain phase to each of the shapes described above, the problem of studying the so-called shape-phase transitions between the various classes of solutions of the Bohr-Mottelson model comes forward. For example a γ-independent potential of the type $V(\beta)=a\,\beta^2 + b\,\beta^4$ is able to generate either a spherical minimum, or a deformed γ-unstable one, depending on the values of the parameters a and b (see Fig. 3). Of course this potential allows one to span the whole range of intermediate cases, including the critical point. In this case one speaks of a U(5)-SO(6) quantum phase transition or a spherical to γ-unstable transition (which is a second-order phase transition in Ehrenfest's classification [6,7]). The critical point, that from the theory of phase transitions is defined as the value of the control parameter for which a given order parameter (or one of its derivatives) manifests a discontinuity, is obtained in the case of a pure β^4 potential. This potential is not soluble analytically, but numerical solutions have been found [8]. Before the numerical solution Iachello (in a series of papers that cover this and other cases) has realized that the pure quartic potential may be approximated with an infinite square well in β, that yields an exactly solvable problem [9]. The analytic solution that he has found in this way was named E(5), because the eigenfunctions, that are essentially spherical Bessel functions, form a basis for the Euclidean group in five dimensions. Another reason to do so is that E(5) is indeed a spectrum generating algebra (In other words the Hamiltonian is a polynomial in the generators of a Lie algebra and this implies an easy calculation of the matrix elements and therefore an easy diagonalization.) for the Bohr Hamiltonian with the infinite square well potential: where the potential is null, the whole equation reduces to just π^2, the five-dimensional vector momentum squared, or, in other words, the generator of translations and rotations in five dimensions, that is the Euclidean group.

Nuclear phases coming from the **quadrupole degree of freedom** have been pictured in a **phase diagram,** called the **Casten triangle**



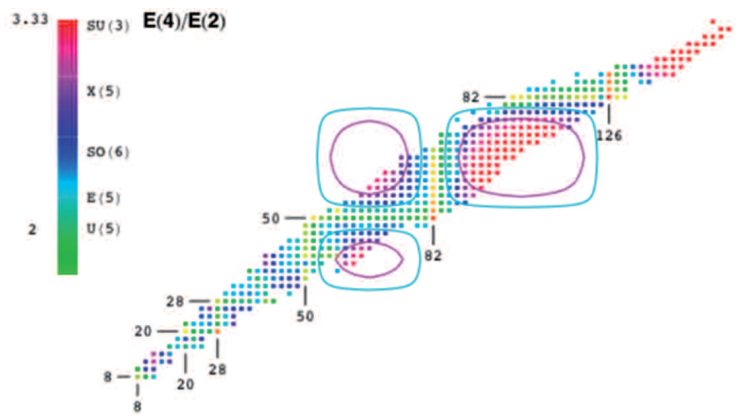
▼ **FIG. 4:** Comparison of energy level schemes of E(5) and IBM with experimental spectrum of 134Ba. Arrows indicate electric quadrupole transition rates, or B(E2) values, in W.u. (see Ref. [10] for details, courtesy of R.Casten).

The E(5) solution is not just a nice mathematical solution of the Bohr Hamiltonian at the critical point of the shape-phase transition between spherical and deformed γ-unstable regimes, but serves as a paradigm for nuclear structure, because it is parameter free (except for an overall energy scale) and gives precise formulas for energy eigenvalues, wave functions, electromagnetic transition rates and selection rules that may be tested against spectroscopic data.

Although, with respect to the collective solution, a correction for the finite number of particles is due (and may be easily done within the IBM), various nuclei have been identified as candidates for this critical point symmetry, as it is now dubbed, notably 134Ba [10] and other isotopes [11]. In Fig. 4 the E(5) spectrum is shown on the left, while the spectrum obtained in the Interacting Boson Approximation considering N=5 bosons is shown in the centre. On the right we have the comparison with the measured spectrum of 134Ba. The symmetry, although slightly broken, can be recognized not only from the relative energy of the various states, but also from the calculation of quadrupole electromagnetic transitions between them, indicated with arrows and other measurable properties such as isomer shifts, transfer intensities and so on (see Ref. [10] for a more complete description of the quantum numbers and notation).

The follow up of the E(5) work has been a similar analysis [12], in which an approximate solution for the critical point between the spherical and axially deformed shapes has been proposed and put in correspondence with some underlying symmetry of an unspecified nature, named X(5).

In this case the potential in β is again an infinite square well, but in order to obtain a minimum around γ=0° a harmonic oscillator is used for the potential in the γ variable. Although a thorough description of this solution would lead us astray from the intended goal of this paper, it must be said that it has been very fruitful in terms of comparison with experiments and the identification of candidates has been quite successful, because spherical nuclei are abundant along closed shells, while axially deformed ones are abundant at mid-shell. Because of the many isotopes that sit in the intermediate region (see Fig. 5), encountering a transitional nucleus there becomes a very likely event.



▲ **FIG. 5:** Ratio of energy of the first 4+ state over the energy of the first 2+ for a portion of the nuclear chart. In abscissa and ordinate we have the neutron and proton number respectively. The various limits and critical points are encoded in the colour bar. Regions where there might be candidate nuclei for the critical point behaviour are indicated with sky-blue and violet for E(5) and X(5) respectively. (Courtesy of P.van Isacker, adapted).

Signature

The easiest experimental signature for each type of behaviour is the ratio of the energy of the first Jπ=4+ states over the energy of the first 2+ state. This is not alone sufficient to ensure that an isotope belongs to a particular class or phase, but is a first pointer to classifying

the spectra and the nature of the nuclear shape. This ratio is plotted in Fig. 5 for a large portion of the nuclear chart as a function of the number of neutrons and protons (in abscissa and ordinate respectively). The ratio for the U(5) case is 2 since the spectrum is harmonic, and examples are found along the lines of magic numbers (closed shells). The ratio for the E(5) case is ~2.09 and corresponds to the sky-blue colour, while for X(5) is around 2.9 and corresponds to violet. The SO(6) limit has a ratio of 2.5, while the pure rotational phases have a ratio of 10/3 ≈3,33 which is found at the very centre of a shell for both protons and neutrons. Other more refined quantities, such as electromagnetic transition rates, isotope and isomer shifts and even pair-transfer intensities may be used to pin down the critical point and the onset of shape phase transitions.

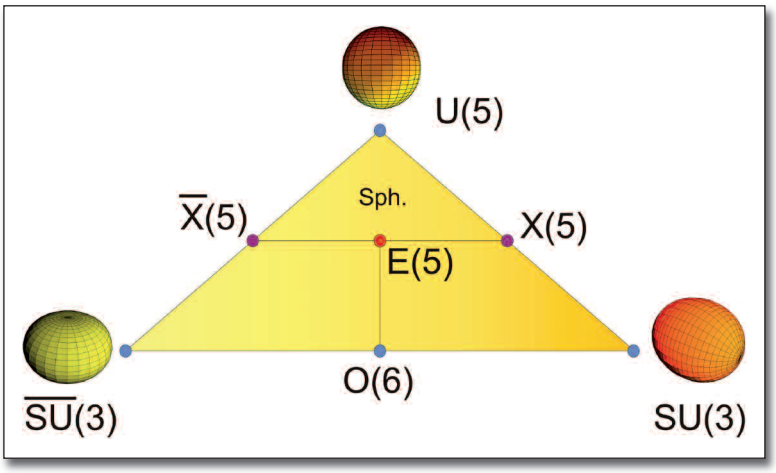
The nuclear phases coming from the quadrupole degree of freedom (either in the collective Bohr-Mottelson description, or in the algebraic IBM) have been pictured in a phase diagram, called the Casten triangle, that has been subsequently enlarged to the extended Casten triangle (see Fig. 6). At the three vertices there are the spherical phase, characterized by U(5), and axially deformed phases. These last two share the same algebra, SU(3), but describe either the prolate (rugby ball) shape or the oblate (mandarin orange) shape. The γ-unstable phase sits on the side between those two, while the X(5) and E(5) critical points are intermediate between the various phases. Although most nuclei cannot be exactly put in correspondence with the special points of the triangle, it is often possible to use those points as benchmarks.

Since the year 2000, these studies have spurred a large number of experiments dealing with a precise gamma-ray nuclear spectroscopy that have been performed or are currently being carried out in major laboratories in Europe and in the rest of the world and they have also promoted a great deal of theoretical interest aimed at better understanding the shape-phase transitions and their underlying symmetries (see e.g. [12]). The main conclusion, that can be drawn from the interplay between the theory of Lie algebras and the exact solutions of simple models of nuclear structure, is twofold: from one side, in a bottom to top fashion, it furnishes a very precise way to classify and give a proper name to the extraordinary variety of observations that have been carried out, but more importantly, in a top to bottom perspective, new mathematical solutions that are inherent to these algebraic models might fuel new waves of experimental campaigns and give us a better understanding of the atomic nucleus.

The overall picture of the quadrupole nuclear collective behaviour, that emerges from the works summarized in the present article, is fairly complete and strongly supported by experimental evidence and gives us a detailed understanding of the nuclear shape and the fascinating mathematics underlying it.

About the author

Lorenzo Fortunato, (B.Sc. in Physics, Torino, Italy 2000 and Ph.D. Padova, Italy 2003) is a researcher within the University and INFN in Padova. His interests span nuclear structure and reactions. Among others these include shape phase transitions, solutions of the Bohr Hamiltonian, algebraic models, cluster models for light nuclei and pairing vibrations. ■



▲ **FIG. 6:** Extended Casten triangle. Spherical and axially deformed phases are indicated at the three corners. The γ-unstable one is on the base while the three critical points are given in violet (first order phase transitions) and red (second order).

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PHYSICS IN DAILY LIFE:

NEW LIGHT

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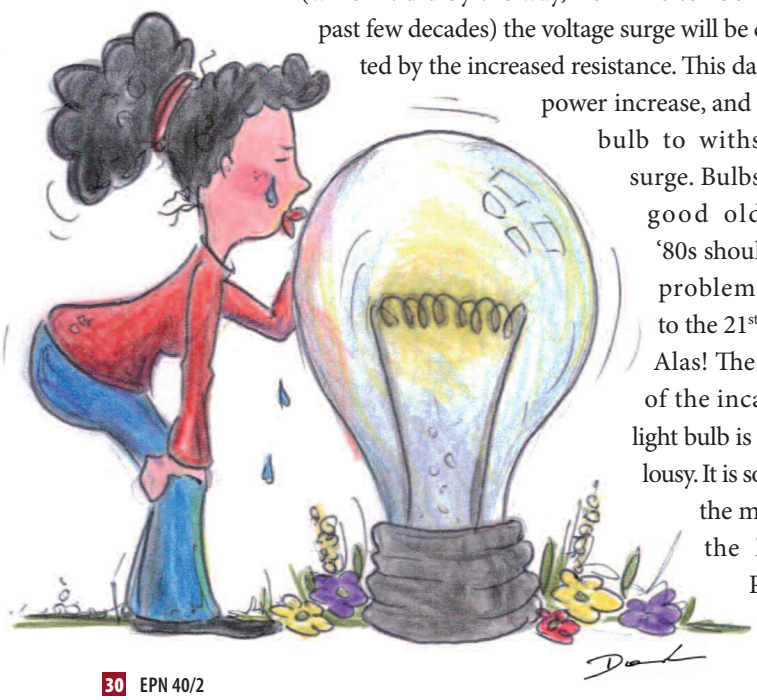
The old-fashioned incandescent light bulb with its Tungsten filament is a marvellous piece of technology. If we switch it on, it needs only a split second to light up our office, our home or our fridge. Sure, this instant reaction is largely due to the low heat capacity of the filament. But there is more to it than most of us realize: Tungsten, like all ordinary metals, has a positive temperature coefficient. Indeed, if we calculate the resistance from the bulb's power and the grid voltage, and compare it with a direct measurement at ambient temperature, we find that the hot filament has a larger resistance by a factor of 20 or so. This means that, if we switch the bulb on, the initial power is very high, making the bulb rush to its operating temperature in no time at all. And the other nice thing is: should the voltage go up for some reason (which it did by the way, from 220 to 230 V over the past few decades) the voltage surge will be counteracted by the increased resistance. This dampens the power increase, and allows the bulb to withstand the surge. Bulbs from the good old '70s or '80s should have no problem adapting to the 21st century.



Alas! The efficiency of the incandescent light bulb is downright lousy. It is so poor, that the members of the European Parliament recently decided to ban the bulb. They have a point. There is no way we can ever make a glowing piece of Tungsten into an efficient light source. For one thing: the emission peak at 3000 K is around 1 μm wavelength, as follows directly from Wien's law. The corresponding emission curve has only a small overlap with our eye's narrow sensitivity curve at around 0,5 μm. And if we go much higher than 3000 K, the filament won't last very long. By invoking halogen vapour to redeposit evaporated Tungsten back onto the filament, we may get a bit closer to the melting point of 3700 K. But even if we were able to find a high-melting-point metal which could be heated to 6000 K (roughly the effective solar temperature, with an emission peak that nicely fits our eye sensitivity), its black-body radiation curve would still be much broader than the eye sensitivity curve, with a lot of energy wasted.

What we need is a smart light source which selectively emits radiation that our eyes can see. And which has no filament that slowly but surely evaporates.

So we turned to gas discharge and invented fluorescent TL lighting long ago, with an efficiency of 100 lumen per watt, and – more recently – its folded version known as the energy saving lamp, reaching 50 lm/W. And, of course, the Light Emitting Diode as its solid-state counterpart, with a similar efficiency, depending on the type. Compare this to a poor 12 lm/W for the good old incandescent bulb!

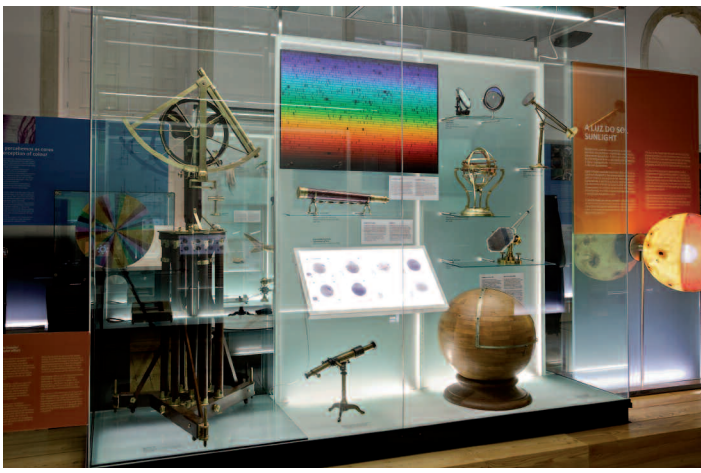
We may not always be happy with politics: when it comes to lighting, however, we have to admit that 'Brussels' has a point. Incandescent light bulbs may be fast and convenient. Their emission spectrum may be nice and continuous. But in terms of efficiency, they are beyond hope. It's about time to kiss that bulb goodbye. ■

THE MUSEUM OF SCIENCE
AT THE UNIVERSITY OF COIMBRA

The Museum of Science (www.museudaciencia.pt) of the University of Coimbra, Portugal, opened its doors to the public in December 2006 (Fig. 1). Part of the excellent collections of the Museum of Physics (see Europhysics News 34/4, 154) from the 18th and 19th centuries are included as well as part of the heritage of the old Astronomical Observatory.

The museum aims at communicating science to the general public, using not only ancient artefacts but also modern museological resources. In 2008 the European Museum Forum distinguished the Museum with the Micheletti-award, a prize for the best European museum of the year in the category of science and technology, recognizing the work carried out by the University to create an innovative museum based on its buildings and collections. The Museum is an important piece of the candidature of the University to the UNESCO World Heritage.

The Museum was planned in two sequential phases, occupying two separate but close buildings. The first phase, called "prefiguration", has its premises in the renewed *Laboratorio Chimico* (Chemistry Laboratory), built in 1722, where a permanent exhibition – *Secrets of Light and Matter* – is shown (Fig. 2). This exhibition surveys the relationship of light and matter, as found in the last four centuries, using a variety of objects and scientific instruments (physics, astronomy, chemistry, mineralogy, medicine, botanic and zoology) of the University collections. A set of interactive modules, sometimes replicating historical experiments, allow visitors to observe, for instance, the decomposition of light or the detection of infrared radiation. There are regular activities devoted to children organized by a specialized educational staff. For instance, since 2009 is the International Year of Astronomy, the Museum is the headquarters of an international project called *The Sky – Yours to Discover*, which asks children to observe and draw the sky.



▲ **FIG. 2:** A part of the exhibition *Secrets of Light and Matter*, devoted to astronomical observations, in particular of the Sun.

The second phase of the Museum, already under way, uses the historical building just in front of the *Laboratorio Chimico*: the former College of Jesus, founded in 1542 and one of the oldest Jesuit colleges in the world. This building, reconstructed in 1772, hosts the Physics and the Natural History Cabinets established in that year. The requalification of the College is a great endeavour, involving not just the renewal of an area of about 13,000 m^2 but also the assembling of the vast scientific collections of the University. The size of the scientific heritage may already be appreciated by digital access (see the Digital Museum of Science at the above site). The museum is in walking distance of other university attractions,

◀ **FIG. 1:** The renewed *Laboratorio Chimico* (Chemical Laboratory) built in 1772, where the Museum of Science of the University of Coimbra opened in 2006 permanent exhibition – *Secrets of Light and Matter*.

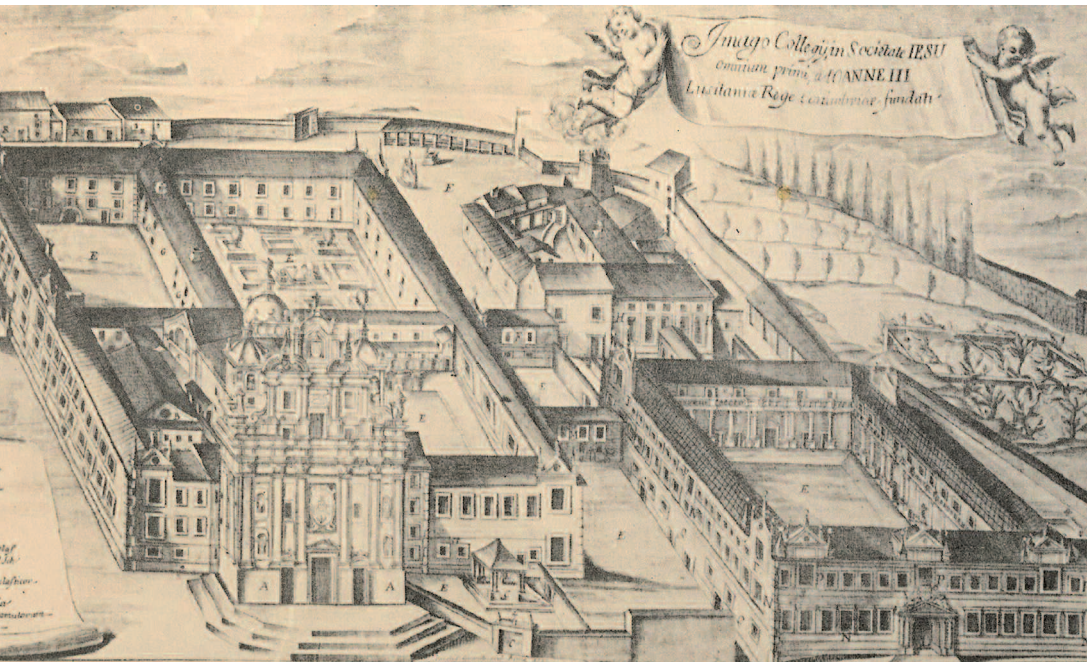
▲ **FIG. 3:** Overview of the large refectory of the Jesuits colleges, finished in 1596, where the exhibition *Secrets of Light and Matter* was installed.

▼ **FIG. 4:** Early 18th century engraving showing, on the left, the College of Jesus, one of the oldest Jesuit colleges in the world, with the "Se Nova" church. On the back of the right-hand side we see the dining room of the two Jesuits colleges, where the Marquis of Pombal built the *Laboratorio Chimico*.

such as the Biblioteca Joanina (Library of V. John, http://bibliotecajoanina.uc.pt/) which was finished in 1728 under the rule of king D. John V, but goes back to the Studies Library created before 1513.

The Coimbra collections of scientific instruments are the oldest and most significant in Portugal, being also relevant at the international level. Its core goes back to the 1772 University reform, at the order of the Marquis of Pombal, the powerful Prime-Minister who established modern teaching and research in Portugal. The Marquis made a deep renewal of the university, with the creation of the Faculties of Mathematics and Philosophy and the reform of the Faculty of Medicine. Having been influenced by the European Enlightenment during his stay as diplomat in London and Vienna, he became in 1750 the prime-minister of D. José I, the successor of D. João V. He gained world fame with the reconstruction of Lisbon after the big earthquake of 1755, which impressed the greatest Europeans minds of the time, such as Voltaire, Kant and Rousseau.

To accomplish his educational and scientific plan, the Marquis ordered a large modification of the College of Jesus (the Order had been expelled from Portugal in 1759), making it suitable to teach the various experimental sciences. This ambitious plan included the creation of the Physics Cabinet, the Natural History Cabinet, the Anatomical Theatre and the Pharmacy Dispensatory. An academic hospital was also set up in the same building. The University was also enriched with new edifices which express, not only the *Laboratorio Chimico*, but also the Astronomical Observatory and the Botanical Garden. The Laboratory, which is contemporary of the most important work of Lavoisier, was one of the most emblematic of the 1772 reform. The final project was made by William Elsden, an English military engineer, at the Casa do Risco (House of architecture) in Lisbon, created in the sequel of the earthquake. The new building was erected at the place of the large dining room of the two Jesuits' colleges (College of Jesus and College of Arts), finished in 1596 (Fig. 4). Nowadays, the architect João Mendes Ribeiro and his team managed to assure the memory of the place, while adapting the space to modern museological requirements and, therefore, making the visit a most pleasant experience. With the planned extension of the Museum of Science to the College of Jesus, this experience will certainly become more memorable.



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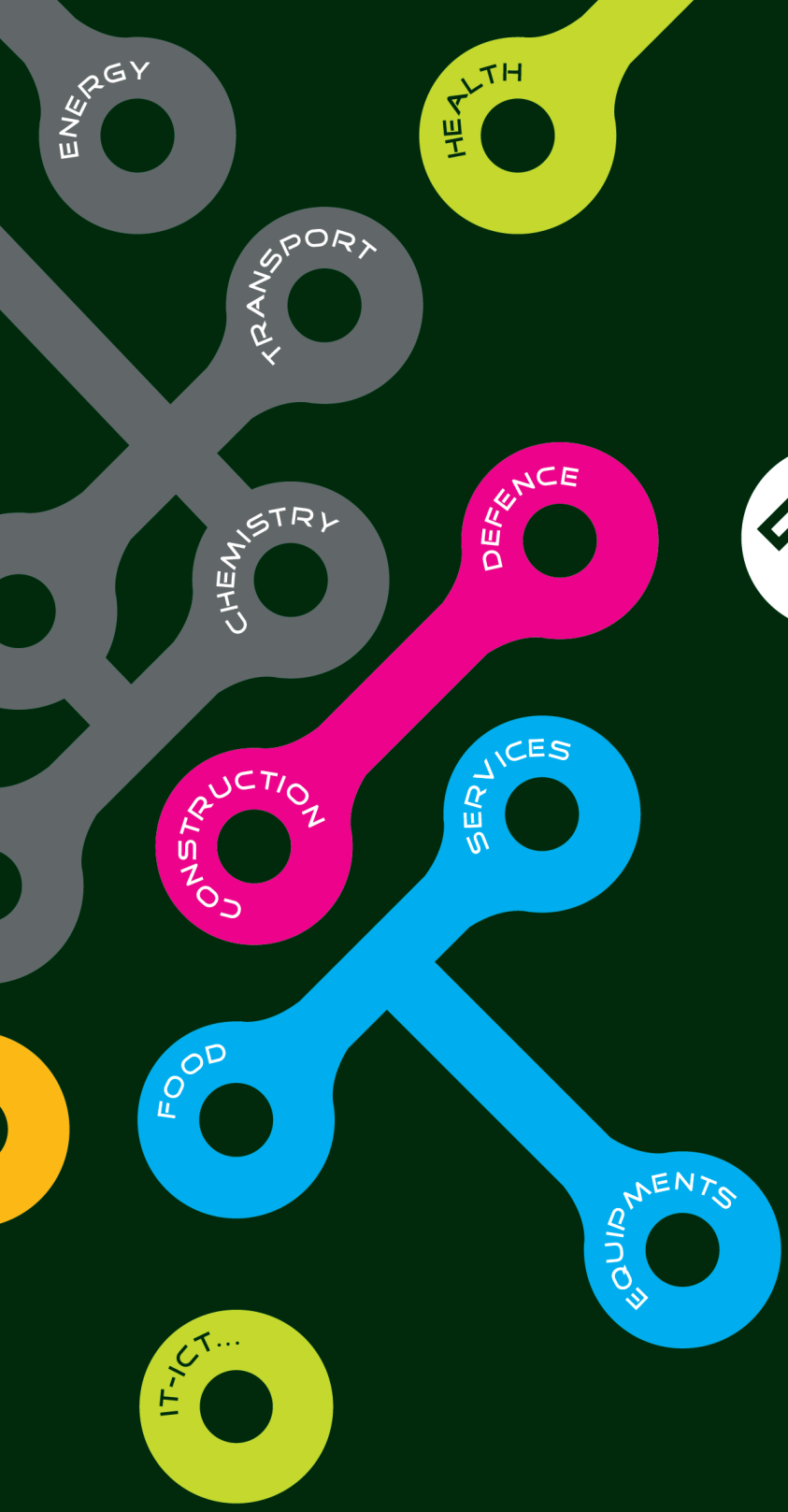

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