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Annual index

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Cover picture: European flags, see p.04 "Historical approach of the Bologna reforms: the case of Physics".

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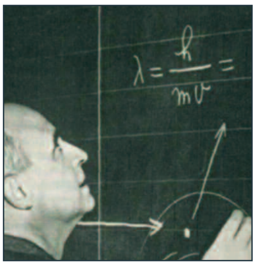
About the 2009 Nobel prize in Physics



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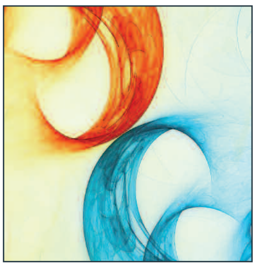
A tribute to Enrico Fermi



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Physics in daily life: Heating problems

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A TRIP TO THE EAST

It is both a duty and a pleasure for your President to participate in many meetings concerning physics, organization of science and physical societies in different countries of Europe and the world. This autumn I travelled east – first to Lithuania, where a joint meeting of physicists from Lithuania and Belarus took place. A meeting on laser optics, a field close to mine, accompanied the conference, "Scientific Research of the Scientists of Baltic Region". Physicists of both countries cooperate - or at least organize common seminars - since years. In Lithuania laser technology is well developed; this can be one of the positive examples of applied optics in Eastern Europe. There are sufficient undergraduate and Ph D students at the physics faculty as well. Additionally, one notices concern for the development of fundamental sciences - for example in Belarus there is an active *Belarusian Foundation for Fundamental Research*, with a physicist as its president.

What should be stressed: physicists of both countries are very interested in the EPS. However, the costs of being an individual member, or associate member for institutions, are too high compared to the fee paid to National Societies. A similar observation can be made in Ukraine, where I visited the Physics Department in amazing Lvov and attended an optics conference in charming Chernovtsy.

Meetings with physicist show a still relatively good state of education and research in both towns. But the complex situation, especially economical, could damage the traditionally good level of physics. The best scientists and students are going abroad, hopefully not forever. Some of them come to Poland; in my own institute we had 30 young citizen of Ukraine in the "best" years. From East Ukraine the best students go to Moscow for their studies.

The conference on Correlation Optics, held in Chernovtsy, attracted good speakers even from Australia, UK, etc (www.itf.cv.ua/corropt09/). The coherent optics laboratory and the publications from the group in Chernovtsy are really interesting – from advanced theory to experimental cancer cell recognition.

The third travel was the longest one - to Vietnam. The Vinh university, with which we (Institute of Physics, Polish Academy of Sciences in Warsaw) have been cooperating for a long time, although mainly uni-directional, invited us for the celebration of the 50th anniversary of the University. On this occasion a workshop on physics took place. The lectures presented there, on optics and solid-state physics, were on an international level.

There is a serious need of experimental equipment as well as big and mid-size laboratories. Difficulties with scientific degrees cause a lot of challenges for all senior and young physicists, if they would like to develop science and education on a contemporary level. Recent possibilities to buy equipment are promising, but there is a lack of scientists having a doctorate, while going abroad for a PhD is difficult.

But now there seems to be green light for education and science in Vietnam. As an example, one year ago a nongovernmental body – the Science Foundation - was established. It is financed by the government, but the Foundation is self-governed by a scientific council, with a physicist as chairman. The first grants were already given, for example for an advanced laser spectroscopy programme in Vinh.

To conclude: the development of science and education seems to have entered a new era, both in the Far East and in the not-so-far East. But in different regions it may move in opposite directions. In any case, the help of European physicists, institutional and personal, in education and science is welcome, needed, and will be surely appreciated. Any ideas and actions in this field are welcome. ■

Maciej Kolwas,
President of the EPS

HISTORICAL APPROACH OF THE BOLOGNA REFORMS: THE CASE OF PHYSICS

The 'Bologna Process' started officially after the Bologna Declaration [Bo99] signed in 1999 in Bologna by ministers in charge of higher education from 29 European countries. However, this movement would not have gained the needed momentum, if the ERASMUS programme had not been started in 1987 with its implications, particularly student mobility. The physics discipline has been soon active in this mobility and has been supportive of the creation of a European Higher Education Area (EHEA) based on international co-operation and academic exchange.

In 1992 a successful '*European Mobility Scheme for Physics Students*' (EMSPS) was established. Prof. E. Heer (*Université de Genève*, CH) previously obtained experience with a student mobility initiative in the Swiss federation among the different language groups. He gave a true impulse to start the activity. Financial support for the project was found in the frame of the ERASMUS programme with the administrative support of the *European Physical Society* (EPS). The physics departments of the hundred participating institutions gained an insight into the structure of the physics studies when organizing the student exchanges. Moreover the scheme was not only relying on support for the then EC and EFTA partners via an *Inter-University Co-operation Project* [ICP, co-ordinated by *Universiteit Gent*, H. Ferdinande (BE)] but also *via* a set of five *Mobility Joint European Projects* from the TEMPUS programme for central and eastern European countries [MJEP, co-ordinated by *Leibniz Universität Hannover*, P. Sauer (DE)], covering the partners in Hungary, Poland, Lithuania, Latvia and Romania.

A successful thematic evaluation conference [Fe95] in the frame of the SOCRATES programme was held in Gent (BE) in 1995. Representatives of 24 western, central and eastern European countries reported on the physics studies and training in their countries, giving the status of the degree programmes, the needs for co-operation and the implementation of those aims in a European perspective. Four themes were identified (curriculum development, intensive programmes, mobility and educational resources) and are still the main topics in the present Lifelong Learning Programme of the EC. This meeting conclude with the creation of a permanent forum and gave the start to the formation of a sustainable network, the *European Physics Education Network* (EUPEN)

In 1996 this consortium (over 100 physics departments in 30 countries) received a three years' grant for an academic network project from SOCRATES. Five working groups were formed (chair & secretary):

1. The student experience [L. Donà dalle Rose (IT) & G. Jones (UK)],
2. Curricula structure and development [J. Dore (UK) & J.-Cl. Rivoal (FR)],
3. Organization of physics studies [E. Cunningham (IE) & A. Konsta (GR)],
4. Career aspects of physics education [Fr. Brut (FR) & J.-P. Hansen (NO)] and
5. Research in physics teaching [M. Vicentini (IT) & R. Pinto (ES)].

During the three annual assemblies, better known as EGF or EUPEN General Forums the following main topics [Fe05] were discussed:

1. 'First-degree' curricula [mostly equivalent to master degree courses],
2. Bologna Declaration,
3. Doctoral studies, as well as the skills & knowledge of ICT in the curricula.

The comparative study of these topics was realised by a set of several questionnaires to the partners. Although the reports could not be regarded as statistically robust, they confirmed that similar teaching/learning outcomes could be achieved through different organisations of studies, teaching methods, and evaluation procedures. The project was able to establish a close link with the students via the *International Association of Physics Students* (IAPS), which took an integral part in our meetings and even made a presentation [Nigel Harris (UK)] at the first EGF97, held in Brugge (BE). From the start also a link with the *American Association of Physics Teachers* (AAPT) was laid.

A (quasi) monthly e-zine, EUPEN ON-LINE, has informed during more than ten years (1996/2008) the contact persons at the partner institutions about European physics education news.

The 'Bologna' period

During the academic year 1999/2000 the results of the previous project were disseminated in three EUPEN regional forums, held in Lille (FR), Poznań (PL) and Barcelona (ES). In the EUA Trends I report [EU99] - under the heading *"Subject-based evaluation at European level"* - our network was mentioned as: "… Such European networks have an important role to play

and should be supported by institutions and governments in their efforts: to gather, publish and disseminate information on study possibilities in Europe in each field of specialisation (as some Thematic Networks established under the Socrates programme have already done, *e.g.* for the field of Physics); …"
A second phase for the EUPEN consortium happened during the three years' contract with the DG EAC of the EC (2000/2003). Almost 150 physics departments from more than 30 "SOCRATES countries" worked in five working groups [chairperson]:

1. Quality assessment and assurance & TEEP2002 (see further) [G. Jones (UK)],
2. First- and second-cycle degree in the context of 'Bologna' & TUNING (see further) [L. Donà dalle Rose (IT)],
3. Networking opportunities for specialisation in physics [E. Cunningham (IE)],
4. Trends of enrolment and destination of students & comparing exams in Europe [H. Latal (AT)], and
5. Multimedia in physics teaching & learning [MP09] [H.-J. Jodl (DE)].

The proceedings of all those forums were published as a series of seven books: *'Inquiries into European Higher Education in Physics'* [Fe05].
From the start in 2000 a close collaboration was established with the *'Tuning Educational Structures in Europe'* ('TUNING') [TU09a] initiatives. For examplethe present author was member of the management committee under the co-ordinators, J. González (ES) and R. Wagenaar (NL). The name for the project *Tuning* was chosen to reflect that universities do not look for uniformity in their degree programmes but simply for points of reference, convergence and common understanding. The TN EUPEN cooperated in synergy as the Subject Area Group (SAG) in physics [chair L. Donà dalle Rose (IT)], together with the other groups in the disciplines of chemistry, mathematics, geology, business, history and educational sciences. Apart from the collaborating efforts executed in common, the physics group developed the study on the physics & astronomy specific competences. The resulting document, *'Reference Points for the Design and Delivery of Degree Programmes in Physics'* [TU09b],

1. Provides the academic communities a transparent guide for planning or re-planning physics degree courses,
2. Presents the main aspects of a physics curriculum and its related opportunities to potential or already enrolled students, and
3. Helps employers and different stakeholders to understand the competences of the physicists they hire. The brochure was validated by a panel of nine physics experts in a joint conference of the physics experts with the physics SAG group.

EUPEN was also partner in the *"Trans-national European Evaluation Project"* (TEEP 2002) [Th04]. This EC-supported *pilot project, executed by the "European Network of Quality Assurance in Higher Education"* (ENQA), investigated the operational implications of a European transnational quality evaluation in three disciplines: physics (five volunteering universities from five countries), history and veterinary sciences. The project was hampered by the fact that, both across the programmes and

▲ **Participants at the EGF2001 Forum in Köln (DE).**

across the disciplines, there existed large differences in the perception of the competence concepts, mainly because the 'Tuning' project was not widespread enough over European Universities. The pilot project proved that better understanding on the meaning of the quality concept should be reached between the group of academics and/or peers on one side and the group of quality evaluators from the agencies on the other side. Progress in this field has been recently obtained [EU09].
The co-operation with the students also extended in the inverse sense. The present author, invited at their annual *International Conference of Physics Students* (ICPS2002) in Budapest (HU) remarked that, because the Bologna Process was hardly visible at that time in most countries, the students were not much interested.
The *'Stakeholders Tune European Physics Studies'* (STEPS) initiative by the *'European Physics Education Network'* (EUPEN) was the name of the Thematic Network (TN) Project in physics, funded within the SOCRATES programme by the EC's Directorate General, Education and Culture (DG EAC) during 2005/2008. STEPS counted 161 physics departments from 37 countries as 'partners' and 10 regional, national or European associations as 'associated partners'.

The objectives were:

1. Enhancing the training of physicists by helping universities to improve their degree course through considering the views of all stakeholders,
2. Helping university physics departments to adapt to the changes required by the Bologna Process and to adopt the *Tuning* methodology, and
3. Developing and supporting projects to encourage school pupils to take an interest in physics and hence to improve the future supply of physicists and teachers.

The initiative had five working groups [chairperson]:

1. *Tuning* and the Eurobachelor® [F. Cornet (ES)],
2. Research & education [I. Sosnowska (PL)/G.V. Pallottino (IT)],
3. Learning methodologies [S. Feiner-Valkier (NL)],
4. Quality assurance & doctorate [U. Titulaer (AT)], and
5. Teacher training/school-university gap [M.-C. do Carmo (PT)].

For detailed conclusions we refer to the website.

The EUPEN network has also been an active partner in the Archipelago of Thematic networks in the fields of Sciences and Technology (TechnoTN) [Te09]. This initiative has been bringing together the experts working in the related fields through their respective TN and offering them a unique opportunity to share and exchange views, case studies and experiences, and from there, to enable them all to disseminate the results of the event through their TN partners and scientific circles.

▼ Foundation of the EUPEN network. From left to right: J. Dore (UK), H. Ferdinande (BE), I. Sosnowska (PL), C. Ferreira (PT) & L. Donà dalle Rose (IT).

At the end of the STEPS project the physics students were so well organised that they started their own *European Physics Students Initiative* (EPSI) [Bi07] which collaborated with EUPEN; they even learned how to submit proposals - unfortunately still non-granted - for their own purposes.

The STEPS initiative is continuing in the STEPS-TWO network (supported by a 2008/2011 grant from the EAC Executive Agency) [Tu08], taking along the aims and goals of the Bologna declaration. The academic network is co-ordinated by the *Universitatea din București* [L. Țugulea (RO)] and contracted by the *Universiteit Antwerpen* [J. Naudts (BE)]. The scheme will support the university physics departments in their strategic institutional development following the structural changes by the Bologna process, with greater European vision to overcome some of the local and national obstacles. It will continue to use the partnership and expertise of the EUPEN consortium. There are three lines of action developing policy recommendations and offering solutions for concrete strategies [chairperson]:

1. Curricula after Bologna and Lifelong learning [U. Titulaer (AT)],
2. Modern teaching methods in physics education and student centred learning [S. Feiner-Valkier (NL)], and
3. Physics teacher education and the European dimension [E. Vitoratos (GR)].

The most recent EGF2009 Forum, focusing on the first topic, was held on 10-13 September in Vilnius (LT) and tried to *answer the question "what after Bologna?"* by offering a set of benchmarks for the physics programmes, posted on the project's website.

Recently the EPS received a three years' grant (2008/2011) to investigate *'The implementation of the Bologna Process into Physics Studies in Europe'*. During 2008, the study [Ke09] was executed by Prof. B. Kehm with the help of the *International Centre for Higher Education Research* (INCHER) of the *Universität Kassel* (DE). It gives the status of the degree structure in the physics bachelor programmes in more than 150 institutions in some 24 Bologna signatory countries. It was concluded that there is already some convergence in the two-cycle structure and the use of comparable credit points for the curricula. More heterogeneity appeared in the definition of student workload, in the pedagogical approaches, and in the forms of assessment. Most physics bachelor programmes attach more importance to the transition to master than to prepare the graduates for the labour market. This EPS project will be continued looking at the masters' programmes in 2009 and at the doctorate studies level in 2010.

The present author was invited again at the latest students meeting [IC09] in Split (HR). This time, the interest in the Bologna reforms by the students was overwhelming and a round table discussion was devoted to the subject.

The future

In parallel with the INCHER study in the same EPS project, the document *'Specification Description for European Physics Bachelor Studies'* [EP09] was recently drafted. It is expected that a series of brochures will be produced covering the Bachelor or first-cycle or EQF level 6, the Master or second-cycle or EQF level 7 (at the end of 2009) and the Doctorate or third-cycle level or EQF level 8 (in 2010). These brochures will represent general expectations about the standards for the award of qualifications at the given level and articulate the attributes and capabilities - *i.e.* the learning outcomes - that those possessing such qualifications should be able to demonstrate.

The Bachelor document has already gone through a long and complex validation procedure and should be finalised very soon.

Recently a group of physics departments and (secondary) schools joined a project overarching the sector of natural sciences, searching to establish a *Sectoral Qualification Framework* in the Natural Sciences, where the study programmes, including physics, will be developed in a European dimension. The project will pay attention to the relation between secondary education and higher education by developing clear reference points and favouring transparency in the transition from secondary to higher education.
In a global perspective the EUPEN scheme will try to co-operate with similar bodies acting elsewhere in the world (*e.g.* Asian Pacific Physics Education Network, Arab Physics Education Network, Council of Inter-American Physics Education Conferences, and American Association of Physics Teachers).
Also the EPS and the *Association of the Asia-Pacific Physical Societies* are happy to announce that the first Asia-Europe Physics Summit "*Physics towards Science Innovations*" will be held in Tsukuba (JP) 24/26 March 2010. ■

Acknowledgements

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About the author

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Nomination call for the 2010 EPS Gero Thomas Medal

The Gero Thomas Commemorative Medal was created in 2000 to honour the memory of G. Thomas, Secretary General of the EPS from 1973 to 1997. He played an essential role in the growth and the development of the Society.

The Commemorative Medal is awarded to individuals for their outstanding service to the Society: E.W.A. Lingeman (NL, 2002), J.L. Lewis (UK, 2005) and G.C. Morrison (UK, 2008). The EPS Executive Committee decided in 2008 to award the G. Thomas Medal on an annual basis. The 2009 recipient was then the computational physicist Dr. Jaroslav Nadrchal from the Institute of Physics at the Academy of Sciences of the Czech Republic (Europhysics News 40/3, 7).

Selection rules

1. The Prize is given once a year
2. The Prize shall consist of a Commemorative Medal
3. The Prize shall be awarded to one (or more) individual(s)
4. The Prize shall be awarded without restrictions of nationality, sex, race, or religion
5. The Medal may not be awarded to any person currently member or having been member of the Executive Committee in the past three years
6. Candidatures are submitted by nominators (Member Societies, Divisions, Interdivisional Groups, Associate Members or Individual Members), as detailed below
7. Only individuals, with substantial service to the Society over a number of years in a variety of roles and whose achievements in physics research, industry or education were remarkable, are eligible for the Prize
8. Nominations shall be reviewed by a Prize Selection Committee appointed by the EPS Executive Committee. The Committee shall consider each of the eligible nominations
9. The final recommendation shall be submitted for ratification to the EPS Executive Committee.

How to submit

To complete the nomination, the nominator is asked to provide the following documents:

- The references of the nominee (Name, first name, postal & e-mail addresses, phone number)
- A suggested citation (maximum 250 characters)
- Nominee's academic and professional background, and professional honours
- Three supporters statements

All proposals will be treated in confidence.
Although they will be acknowledged there will be no further communication.

Nominations should be sent before 15 January 2010 to:
G. Thomas Prize Selection Committee
Chair: Prof. H. Ferdinande (hendrik.ferdinande@ugent.be)
Universiteit Gent, Proeftuinstraat 86
BE-9000 Gent, Belgium.

ABOUT THE

2009 NOBEL PRIZE IN PHYSICS

THE 2009 NOBEL PRIZE IN PHYSICS (I)

NOBEL COMMITTEE REWARDS RESEARCH IN TECHNOLOGY

The Nobel Prizes in Physics of 2009 have been awarded for two scientific developments that have a profound impact on both consumer technology and scientific research. Charles K. Kao of the Chinese University in Hong Kong was awarded the Nobel Prize "for groundbreaking achievements concerning the transmission of light in fibres for optical communication." The second half of the prize was awarded to two researchers from Bell Labs, Willard S. Boyle and George E. Smith "for the invention of an imaging semiconductor circuit, the CCD sensor." Although the importance of the rewarded work is evident, it came to many as a surprise. It was a surprise to Carlo Séquin, now at the College of Engineering at the University of California at Berkeley, and who joined Bell Labs after receiving his PhD and started work on the CCD. "My reaction was of absolute delight, I found out that the work we did was actually worth the Nobel Prize," says Séquin.

"I think it is great to give a prize for something that is technology, certainly for the science that it enabled," says Steve Howell, an astronomer at the Planetary Science Institute in Tucson, Arizona.

For astronomers, the invention of the CCD was indeed a revolution. For Dietrich Baade, the leader of the Optical Detector Team of the European Organisation for Astronomical Research in the Southern Atmosphere (ESO), in Garching, Germany, it changed entirely his work. "This has been the most important development in astronomy the last 30 years or so, if not more, for the simple reason that the predecessor of all the electronic detectors was the photographic plate, and the quantum efficiency of the electronic plate was between 1 and 3 percent. Now, with the solid-state detector, the quantum efficiency reaches almost 100 percent," says Baade. Unlike photographic plates, CCDs allow the repeated exposure of the same area of the sky, making extremely faint objects visible. "The ultra-deep field images obtained with the Hubble Space Telescope are the result of sixty hours of observations– a tremendous number." says Baade.

Howell still remembers how the initial design of the Hubble Space Telescope incorporated photographic plates that would be parachuted to Earth or picked up by visiting crews. "The study of distant supernovae, dark energy and dark matter, none of this would have been enabled without CCDs," says Howell.

The commercial impact of optical fibres is even more important than that of CCDs, but the impact on scientific research is definitely as great. The fast transmission of data in fibres not only allows the setting up of super-fast networks like "the grid" developed by CERN for the distribution of data obtained with the LHC, but also of "virtual observatories" in astronomy and other areas of science.

▼ Charles Kao in his laboratory at the Standard Telecommunications Laboratory in the U.K. in the 1960s. (European Pressphoto Agency)

Direct applications of optical fibres also abound, in photonics, laser research, and even in telescopes. Baade explains how the spectrograph used in the search for exoplanets with HARPS (High Accuracy Radial Velocity Planet Searcher) is connected via optical fibres to ESO's 3.6-metre telescope at the La Silla Paranal Observatory in Chile. The individual fibres collect the light of a large number of stars, and carry the light to a spectrograph mounted in a vacuum vessel, making the extremely sensitive instrument independent of telescope motions and temperature changes.

Unfortunately, the nomination of Boyle and Smith for the development of the CCD became the subject of a controversy. During the days following the announcement of the Nobel laureates early October, several researchers questioned on a blog of *IEEE Spectrum* whether the duo really could be viewed as the inventors of the CCD. "The comments were flying back and forth, there is no doubt that there is a controversy," says Séquin. In fact Boyle and Smith were working on a so-called "bubble memory" for computers, and not on an imaging device. "If you are interested in the basic concept of the charge transport, then I think it is absolutely reasonable to pick Boyle and Smith because they had this crucial discussion in their office that led to this idea," says Séquin. "But if you read the report of the Nobel Committee, it is 90 percent about image sensors and how to make image sensors of high resolution," says Séquin. It was a colleague of Séquin at Bell labs, Michael Tompsett, who in fact built the first CCD, and who applied for a patent for the device. It was also Tompsett who devised the technology for reading out the information stored on the CCD. "This principle was clearly invented by Tompsett," says Séquin.

According to Govind Agrawal, who leads the Nonlinear Fiber Optics Group at the University of Rochester in Rochester, New York, the Nobel Committee generally divided the prize between the team who got the idea and the team who implemented the idea. "In this case they didn't do that." he says. And he also comments on the fact that the 1966 paper by Kao [1], cited by the Nobel Committee, in which he outlines how optical fibres can transport signals over long distances, also has a co-author, George Hockham, who doesn't share the Nobel Prize.

It is clear that the researchers who feel left out are the victims of the rule of limiting the Nobel Prize to maximally three recipients. Increasingly, advances in technology and science are the result of large teams. "Clearly the development of an honest-to-God viable CCD camera involved in the order of 200 individuals," comments Séquin. Perhaps the Nobel Committee should relax its limitation on the number of nominees. ■

A. Hellemans

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THE 2009 NOBEL PRIZE IN PHYSICS (II)

CHARLES KAO, PIONEER IN OPTICAL FIBRES

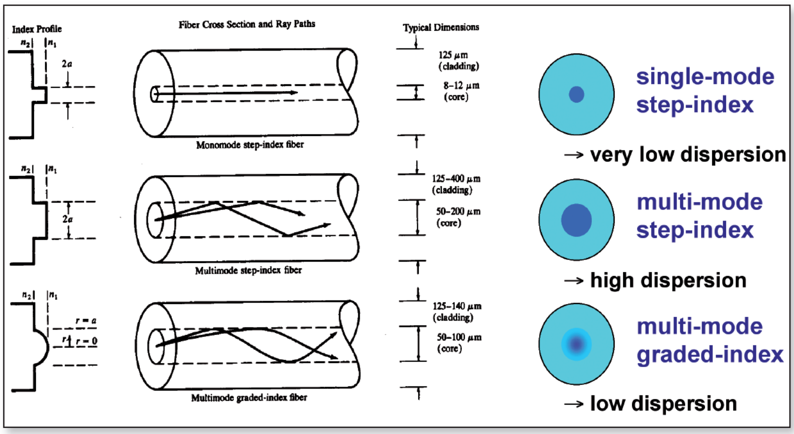
the world is hanging on a tiny thread, a thread of glass. Optical fibre is vastly deployed all over the world, to carry our telephone conversations, computer data, TV signals, the internet with its exploding gamut of services, etc. Our economic, social and cultural activities would come to a standstill without the huge communication streams which the tiny silica glass fibre is able to carry. When Samuel Morse introduced the telegraph and Alexander Graham Bell the telephone, the world was dependent on copper wires. And still large parts of the communication networks are using copper, in particular the twisted-pair telephone lines and the coaxial cable CATV lines connecting the users' homes. Electrical signals get attenuated on the lossy copper lines, necessitating lots of amplifiers all over in the networks. The bandwidth of these lines is quite limited, and is running out of steam in view of the fast growing capacity needs of the internet. Moreover, as the world's resources are expiring, copper gets ever more expensive. Charles Kao, who was born in 1933 in Shanghai, and got his PhD degree in Electrical Engineering in the Imperial College London in 1965, recognized these shortcomings already in the mid 60's. He worked as an engineer in Standard Telephones and Cables (STC) in Harlow, UK, and there he developed his groundbreaking ideas of how to carry light with extremely low losses through glass fibre. He first presented his results in January 1966 in London to the Institute of Electrical Engineers (IEE).

Low-loss light guiding

The guiding of light in curved media was already observed much earlier, *e.g.* by noticing that in illuminated fountains light was guided by the curved water beams. The light guiding is actually realized by 'total internal reflection': light propagating in a material with a high refractive index is reflected at the interface with ▮▮▮

a medium with lower refractive index, provided that the incidence angle on this interface is larger than the critical angle. As this reflection is very efficient and causes negligible losses, light can be confined and guided through the water beam. Obviously more stable solutions than water beams are needed, so similar experiments were done with homogeneous threads of glass. Endoscopy could be done with many of these glass threads united in a single cable. However, small scratches and other irregularities at the surface of the glass destroy the total internal reflection process, and light leaks out. Hence the losses of such homogeneous threads were too high for guiding light over larger distances. Moreover, impurities in the glass itself contributed to the losses. Charles Kao came up with fused silica (silicon dioxide) as the perfect material for very low loss light guiding. And the fibre structure itself should not be a homogeneous thread, but should have an inner core having a high refractive index, surrounded by a glass cladding with a lower index. Thus the boundary was nicely protected and could serve as a reliable close-to-perfect mirroring surface for guiding the light beam. Kao's claim which he presented in 1966 was that, with fused silica glass and the core-cladding structure, losses of less than 20 decibels per kilometer should be feasible, *i.e.* more than 1% of the light power should still remain after propagation through 1 kilometer of fibre. In 1970, Keck and co-workers at Corning

▼ Professor Charles Kao (third from right) poses shoulder-to-shoulder with students from the Chinese University in Hong Kong on the first day of the 1994-95 academic year. Copyright © The Chinese University of Hong Kong



▲ **FIG. 1:** Silica optical fibres (diameter 125µm each)

Glass in the US indeed demonstrated light guiding in such optical fibre with less than 20 dB/km loss.

Modern optical fibre has a standardized outer diameter of only 125 micrometer, within 1 µm tolerance. This is about the thickness of a human hair (see Fig. 1 and 2). Regarding attenuation, it has made a huge progress since its invention, while still following Kao's principles. It now conveys more than 95% of the light through 1 kilometer of fibre, *i.e.* it has a loss of less than 0.2 dB/km. This has only been possible by bringing the purity of the silica glass to the extreme, using precisely controlled environmental conditions, very sophisticated chemical vapour deposition techniques for building a structured perform, excluding every tiny amount of water, and drawing the preform into a very tightly controlled fibre.

The diameter of the fibre's core has a major impact on the light guiding properties: when it is on the order of the wavelength, it can be shown that the fibre is able to guide light only in a single mode: hence it is called a single-mode optical fibre (see Fig. 1). When it is much thicker, many more modes can be guided: a multimode fibre. Each mode has a different propagation time; thus an optical pulse, which is guided by these modes, will get dispersed and is broadened when it arrives at the fibre's end. When pulses broaden, they cannot be put closely together anymore without serious overlap. Hence this modal dispersion phenomenon limits the rate at which pulses can be transmitted, and thus the bandwidth of the fibre. The modal dispersion can be reduced by accelerating the light rays which are making the larger excursions when travelling through the core, thus reducing the refractive index of the core towards the cladding, see Fig. 1. Such 'graded-index multimode fibre' shows a clearly larger bandwidth than its step-index counterpart. Obviously, a single-mode fibre shows hardly any pulse broadening, and thus has the ultimate bandwidth.

Single-mode fibre is by far the most wide-spread fibre type. Multimode fibre is only applied for shorter links, such as in in-building networks. Thanks to its larger core, it is easier to connect than single-mode fibre.

Dispersion and losses

The bandwidth of single-mode fibre is mainly limited by material dispersion (since the refractive index of the silica glass is slightly dependent on the wavelength) and by waveguide dispersion (since the electrical field spreads out from the core into the cladding, and this spreading becomes larger at increasing wavelength). Material dispersion and waveguide dispersion have opposite signs, and can cancel each other. For silica glass, this happens at a wavelength of about 1.31 µm, the so-called 'zero-dispersion wavelength'. At this wavelength, the fibre reaches its ultimate bandwidth,

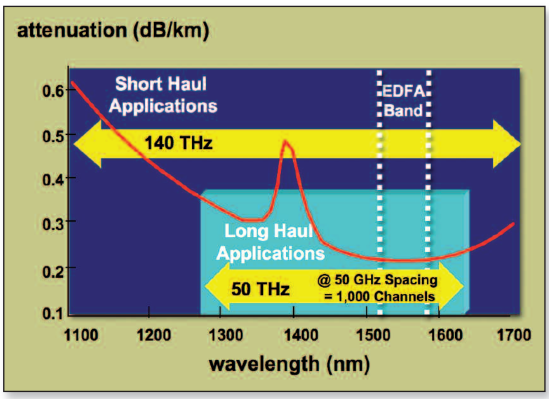
and the bandwidth of the whole fibre link is then only limited by the spectral purity of the laser transmitter.
The fibre's losses depend on the wavelength of the light, and reach their lowest value around 1.55 µm, which is in the near infra-red. As Fig. 3 shows, the low-loss wavelength region of the fibre represents a huge optical frequency range, and thus an extremely large capacity for guiding telecommunication signals. A laser diode, which is another crucial element in an optical fibre communication link, can send light pulses at a very high repetition rate, at tens of giga-Hertz, but only occupies a tiny part of this optical frequency range. But many of these laser diodes, each operating at a slightly different optical frequency, can be put in parallel and thus together convey massive amounts of data. Using this so-called 'wavelength division multiplexing', in the laboratory transmission has been achieved with speeds exceeding 21 terabits per second. Such a capacity would allow one half of the world's population to have a phone conversation with the other half, just through one tiny silica optical fibre as thick as a human hair!
Nowadays optical fibre is installed all over the world. The total length amounts to some 1 billion kilometers, 25000 times the circumference of the earth! Many fibre links are connecting the continents together; *e.g.*, the transatlantic links bridge the ocean between Europe and North America, ca. 6000 km, and the transpacific links between the west coast of the US and Japan, ca. 9000 km, with an intermediate landing point in Hawaii. Although the fibre has very low losses, such distances cannot be bridged without amplification. The advent of the optical fibre amplifier, in particular the erbium-doped fibre amplifier (EDFA) was another landmark in the evolution history of optical communication systems. When doped with the rare earth material erbium which is brought into an excited state by optical pumping with another laser, the doped optical fibre can amplify optical signals directly without converting them first into electrical signals. Many wavelength channels can be amplified all-optically and simultaneously, which makes such an optical amplifier an essential component in long-haul wavelength-multiplexed systems.

Fibre-to-the-home and fibre-in-the-home

Whereas silica fibre has conquered telecommunication networks in the long-haul parts, spanning oceans, continents, but also countries and cities, the final drop to the user's home is in most places still on twisted-pair copper lines and/or coaxial copper cables. This final access drop is more and more becoming the bottleneck in offering high capacity to the user. Hence fibre is now increasingly being installed all the way to the homes in access networks, replacing the copper lines, and by virtue of its tremendous capacity hosting all the services offered by the copper media (triple play: video, voice, and data) and any service yet to come! In Japan, fibre-to-the-home has already outnumbered the copper twisted pair connections (the digital subscriber line, DSL). And the US and many European countries are progressing in the same direction. Connection speeds to the home are typically 100 Mbit/s both to and from the home; in Japan, even 1 Gbit/s is introduced.
But Fibre to the Home is not the end game yet in the quest of bringing the ultimate communication highway to the user. After having reached the doorstep, the highway needs to be extended into the home, up to the devices of the user himself. Thus research is now being directed to optical fibre systems for in-home, where it becomes crucially important to make the system robust, and easy to install, preferably in a do-it-yourself fashion. Silica fibre is brittle and has to be installed with precision tools and by skilled personnel. As an alternative, plastic optical fibre (POF) is coming up, which can be made much thicker, and is ductile. This makes it much easier to handle and to install, even by unskilled persons. Its losses are by far not as low as those of silica fibre, but as in-home link lengths are short, that is not a show-stopper. Like the silica fibre proposed by Kao, also the POF has a core-cladding structure. Its large diameter causes a high modal dispersion, and thus severely limits its bandwidth for longer lengths. But again, lengths are short, and thus this is not lethal. Special techniques are being developed to convey Gbit/s

▲ **FIG. 2:** Light guiding by optical fibres ©istockphoto

▼ **FIG. 3:** Attenuation of silica single-mode fibre .



data streams over POF networks. Also techniques are being investigated to carry microwave radio signals over the fibre in order to meet the user's needs for broadband wireless communication without having to put comprehensive microwave radio equipment everywhere.

So by pioneering optical fibre, Charles Kao has opened the road towards real broadband communication, where the sky is the limit, and light is shining into a bright future where we can communicate with each other without any borders! ■

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About the author

Ton (A.M.J.) Koonen is a Full Professor at Eindhoven University of Technology, in the Electro-optical Communication Systems Group, being Chairman of this group since 2004. He worked for over 20 years in applied research in broadband telecommunication systems: as a member of technical staff at Philips Telecommunication Industry, as technical manager with Bell Laboratories in AT&T Network Systems and in Lucent Technologies. His current research interests include broadband communication technologies and networks, in particular fiber access and in-building networks, radio-over-fiber networks, and optical packet-switched networks. Prof. Koonen is a Bell Laboratories Fellow since 1998, an IEEE Fellow since 2007, and an elected member of the IEEE LEOS Board of Governors since 2007.

THE 2009 NOBEL PRIZE IN PHYSICS (III)

W. BOYLE AND G. SMITH FOR THE CCD

October 6th, 2009 was a great day for the solid-state imaging community. The Nobel Prize in Physics went to Willard Boyle and George Smith, two Bell Labs co-workers who invented the Charge-Coupled Device (CCD). The CCD has created a revolution in science and technology as well as in society at large.

I am wondering whether W. Boyle and G. Smith ever realized that their invention would have such a great impact:

- on society : these days everyone has a digital still camera, many have a camcorder all provided with a CCD, some even with three CCDs. All TV images we see today are being captured by means of CCD cameras; many medical diagnoses are relying on CCD images as well. Other application fields are security, astronomy and scientific cameras. In many applications these days CCDs are being challenged by CMOS (Complementary Metal Oxide Semiconductors) image sensors, but it can easily be understood that CCDs paved the way in solid-state imaging, for CMOS as well;
- on the semiconductor business: many companies made quite a profitable consumer business out of CCDs. Examples are Sony, Panasonic, Sharp, Toshiba, NEC, FujiFilm, Kodak, Philips, E2V, Fairchild, DALSA, LG, Thomson, Sarnoff, SITe, Ford Aerospace;
- on the imaging technology: after the introduction of the CCDs, the classical imaging tube quickly disappeared from the scene. CCDs are more compact, lighter in weight, less power hungry, lower supply voltage, no burn-in effects, no image lag, no maintenance and immune to electromagnetic fields. CCD not only had advantages... but even a lower price. The CCDs opened a great new field of imaging applications that were never possible without solid-state image sensors;
- on the scientific and technical community: the basic CCD invention of Boyle and Smith was a great inspiration for many other great engineers: Walden invented the buried channel CCD, Esser invented the peristaltic CCD, Kosonocky the floating diffusion and White added the correlated-double sampling. But the CCD performance improved quite a lot after the introduction of the pinned photodiode by Teranishi. From that moment, the CCD business really started to boom. Many other important inventions were inspired by the work of W. Boyle and G. Smith;

▼ The two inventors of the CCD with one of the very first CCD cameras, developed by Bell Labs, illustrating their great invention.

▲ **FIG. 1:** Shown here is a 48 Mpixel CCD imager with a size of 48 mm x 36 mm, used in highest-end digital photography (courtesy DALSA, Eindhoven).

Principle of CCD

A Charge-Coupled Device essentially consists of a 2-D array of tiny pixels which convert light into electrical charge (see Fig. 1). Each pixel may be considered as a small group of capacitors carrying a charge. The working principle of a CCD is based on the transfer of charge packets from one capacitor to the next one. The charge is thus transported across the array, and read out at one corner. Pixels located close to the output amplifier have to undergo just a few transport cycles, while the charge of pixels located at the far side of the output stage has to move over quite a long distance towards the output. The image captured by the CCD can be easily reconstructed based on the fact that the pixels become available at the CCD output in a serial way, and in a similar sequence they are displayed on a monitor.

The transport takes place in the silicon material, and is driven by digital pulses. In its simplest form, every CCD pixel is composed out of 4 of such capacitors. With 4 capacitors per pixel, the charge packets can be shifted from one pixel to the next one without being mixed up. Every capacitor can be extremely small; for a classical consumer imager, the pixels go down to 2.0 µm or even less. That means that the individual CCD capacitor is less than 0.5 µm. Note that this is just about the wavelength of visible light.

Fabrication and performance

The design, lay-out and fabrication of these capacitors needs to be done in such a way that it allows a smooth transfer of the charge packets. This transport is not perfect. If its efficiency is not 100 %, some electrons from the charge packets will get lost. In the very early days of the CCDs, the transfer efficiency was about 99 %, but in modern CCDs the transfer efficiency can be as high as 99.99999 %.

On one hand, the industry tries to make the pixels as small as possible, but on the other hand, the number of pixels put on a single CCD chip is increasing. Consumer devices have pixel counts up to 14 Mpixels, but imagers for professional use (*e.g.* astronomy, video-grammetry) have pixel counts ranging to over 150 Mpixels. Taking into account the 4 capacitors per pixel, this gives rise to over 600,000,000 individual capacitors on a single chip!

With respect to the performance of the CCDs, in many aspects they perform as well as the human eye (*e.g.* sensitivity, low-light level imaging, speed). In some aspects the CCDs do even better than the human eye (noise performance, radiation hardness), but in others, the CCDs still can learn from the human eye (power dissipation, parallel processing of the information).

Future perspectives

CCDs do need a dedicated production process to fabricate the image sensors, and unfortunately, these processes are not available on every corner of the street. This observation makes the CCD rather expensive compared to its competing technology, that being the CMOS image sensor. Especially for consumer devices (*e.g.* mobile phones), the outstanding imaging performance of the CCD cannot compensate for the cost difference between CCDs and CMOS image sensors. But on the other hand, for very specific market segments as well as for professional applications, the CCDs are superior over CMOS image sensors (*e.g.*, broadcast applications, astronomy, medical instrumentation; see examples in Figs. 2 and 3). Their image quality is better and the cost advantage of CMOS technology is much less or even non-existing.

Although the CCD is celebrating its 40th anniversary, it still deserves its place in the digital imaging business. ■

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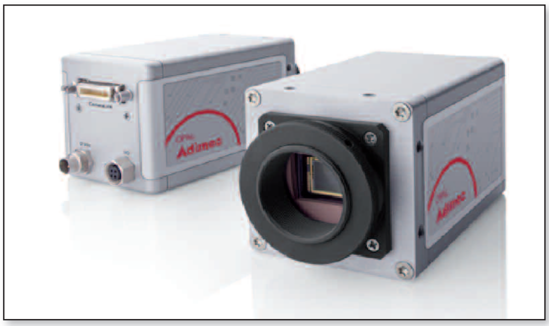
About the author

Prof. Albert J.P. Theuwissen (1954) received his PhD in electrical engineering from the Catholic University of Leuven (Belgium). As of 2001 he is part-time professor at Delft University of Technology (Delft, Netherlands) where he teaches courses in solid-state imaging and coaches PhD students in their research on CMOS image sensors. He is presently running his own company "Harvest Imaging", focusing on training, teaching and coaching of people active in the field of digital imaging.

▲ **FIG. 2:** HDTV camera containing 3 CCD imagers. The pixels of the imagers are designed in such a way that the camera can be used according to different HDTV standards (courtesy Grass Valley, Breda).

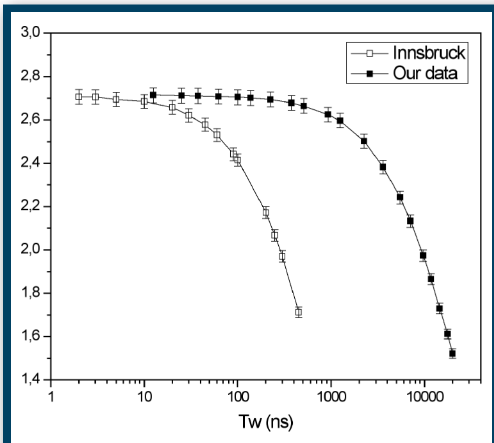
▼ **FIG. 3:** CCD cameras intended for industrial vision applications. The imagers have pixel counts in the range of 1 Mpixels - 8 Mpixels and can produce monochrome and colour images at higher frame rates (courtesy of Adimec, Eindhoven).



Time stamping in **EPRB experiments**

The Einstein-Podolsky-Rosen (EPR) paradox implies a contradiction between Quantum Mechanics (QM) and the basic notion of the properties of natural phenomena. Many experiments measuring stationary probabilities have confirmed the QM predictions, but "the vital time factor" (as Bell named it) has been left unexplored. The so-called non-ergodic theories (NET) reconcile QM with the intuitive view of the world by hypothesizing that the apparent randomness at the quantum level is the consequence of some complex underlying dynamics that may be revealed by a time series analysis. A time-resolved record of the data, or "time stamping", may therefore be essential to elucidate the EPR mystery. We show how a time stamped setup of satisfactory performance can be built with accessible means. We use it, jointly with the raw data of an experiment performed under strict Einstein locality [Weihs et al., *Phys.Rev.Lett.* **81**, 5039 (1998)] to study a class of still untested NETs. These NETs change the probability of coincidence by displacing the photons' detections in time, in-or-out of the time coincidence window T_w, to mimic the QM predictions. The emitted photons being detected, these NETs cannot be disproved by measuring average rates, even in ideally perfect setups. But, in a time stamped file, T_w can be varied at will. Any correlation between T_w and some hypothetical hidden variables is impossible. Then, under fairly general assumptions, it is shown that if the usual correlation parameter S drops at some value T_w, then it should drop again at about $T_w/3$. In the figure it is shown, from the two very different experimental setups, how that second drop is not observed. Therefore, this hardest-to-beat hidden variable theory is disproved, illustrating the power of time stamped setups. ■

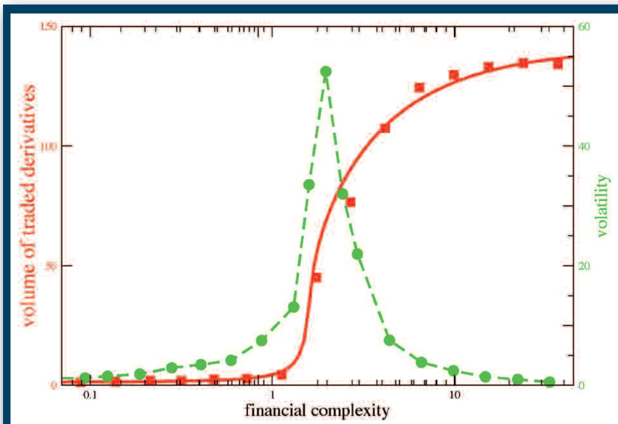
▮▮▮ **M.B. Agüero**, **A.A. Hnilo**, **M.G. Kovalsky** and **M.A. Larotonda**,
'Time stamping in EPRB experiments: application on the test of non-ergodic theories', *Eur. Phys. J. D* **55**, 705 (2009)



◄ The parameter S as a function of the time window size T_w experimental results. Error bars are indicated.

Excess of financial tools **against market stability**

The proliferation of financial instruments – assets, derivatives, securitized loans, etc – provides more means for risk diversification, thus making the market more efficient and closer to the theoretical limit of complete markets, where risk can be eliminated altogether. This conclusion relies on the assumptions of perfect competition and full information. We contrast this picture with a simple model of the market as an interacting system, where prices are affected by trading on the underlying and on derivatives. In this setting, the application of statistical mechanics of disordered systems shows that the proliferation of derivatives brings a market closely resembling the efficient arbitrage-free, complete market described by Asset Pricing Theory. However, the same region of the phase space is also characterized by a phase transition between a supply-limited equilibrium to a demand-limited one. Close to the transition, small perturbations in the risk perception of banks can provoke dramatic changes in the volume of traded derivatives, and large fluctuations are observed in response functions.



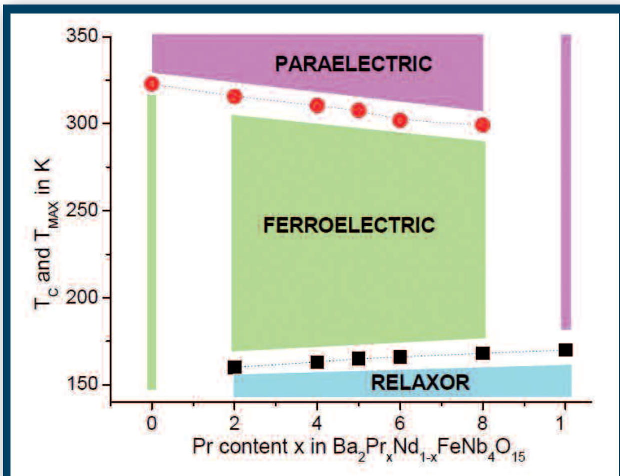
▲ Trading volume in derivative market (left axis) as a function of financial complexity (which is proportional to the number of different derivatives traded). Analytical results (full line) are compared to numerical simulations (red squares). Market volatility (right axis) has a pronounced peak at the phase transition point.

The uncontrolled proliferation of financial instruments (Fig.) has two main consequences: i) it erodes systemic stability, driving the market to a critical state characterized by large susceptibility, strong fluctuations and enhanced correlations, and ii) it provokes a sharp rise in trading volumes in derivative markets. This suggests that market completeness may not be compatible with a stable market dynamics. Therefore, financial stability acquires the properties of a common good, which suggests that appropriate measures should be introduced in derivative markets, to preserve stability. ■

▮▮▮ **F. Caccioli**, **M. Marsili** and **P-P. Vivo**,
'Eroding market stability by proliferation of financial instruments', *Eur. Phys. J. B* **71**, 467 (2009)

Ferroelectric correlations in materials

In relaxor materials, short range dipolar interactions at the mesoscopic scale lead to broad temperature anomalies of the dielectric properties, to large dielectric dispersion and to the absence of a macroscopic polarization. On the other hand, ferroelectrics exhibit a spontaneous polarization resulting from long-range dipolar interactions. It is usually very difficult to make these two behaviours – relaxor and ferroelectricity - coexist in the same material. The purpose of this work is to process a novel solid solution $Ba_2Pr_xNd_{1-x}FeNb_4O_{15}$ making it possible to show such coexistence.



▲ Qualitative phase diagram of $Ba_2Pr_xNd_{1-x}FeNb4O_{15}$ showing coexistence between ferroelectricity and relaxor state in the intermediate composition range.

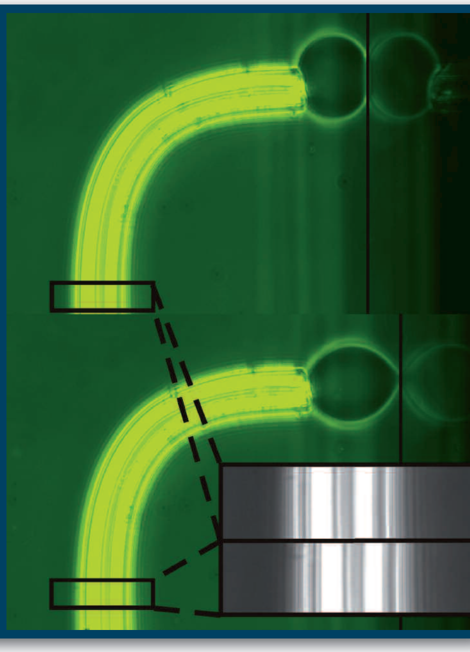
$Ba_2NdFeNb_4O_{15}$ Tetragonal Tungsten Bronze niobate is a ferroelectric (T_C=323K) whereas $Ba_2PrFeNb_4O_{15}$ is a relaxor (T_M=170K): the flexibility of the open TTB network allows the ferroelectric to relaxor crossover on scanning the composition from Nd to Pr in the new $Ba_2Pr_xNd_{1-x}FeNb_4O_{15}$ solid solution. In that case, the ferroelectric as well as the relaxor temperatures of the end members are almost unaffected: the Praseodymium substitution disrupts the long-range ferroelectric order at low temperature, resulting in the coexistence of relaxor and normal ferroelectric dipolar states in the intermediate composition range. Observation of ferroelectric hysteresis loops, and modelling of the relaxor behaviour using the Vogel-Fulcher law, allow unambiguous identification of both states. In this system however, the relaxor to ferroelectric transition is observed with increasing temperature.

This coexistence and the crossover from long range to short range order are ascribed to the TTB framework which is much more flexible than the largely studied perovskite structure. ■

▮▮▮ **E. Castel**, **M. Josse**, **D. Michau** and **M. Maglione**, 'Coexistence of long and short range ferroelectric correlations in a single-phase material', *J.Phys. :Condens. Matter* **21**, 452201 (2009).

Adhesion and membrane tension of cells

To understand many biological processes, and the interaction between cells and materials, we need to understand the way cells stick to each other and to substrates. A new technique to characterise this adhesion combines the best attributes of two previously developed methodologies, the micropipette aspiration techniques and the use of atomic force microscopy. As in the micropipette technique, slight suction is applied to a pipette that is ~ 10 µm in diameter in order to capture a single cell. A pipette is bent into a long thin L-shaped cantilever so that, as in an AFM, the force felt by the cell as it interacts with the substrate can be measured by the micropipette deflection (MD); this method has the advantage over the classical micropipette technique that the force is known through-out a binding-unbinding experiment.



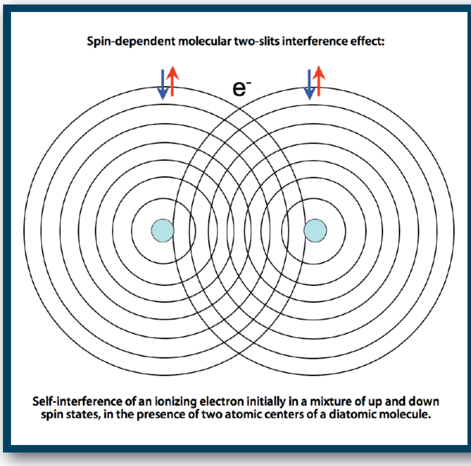
► Image of a liposome and its reflection in the substrate during a push-pull (top-bottom) cycle. The micropipette deflection is clearly visible in the enlarged inset. The vesicle is ~ 30 µm in diameter.

We have tested the MD methodology with measurements on a model cell, a liposome, and living cells. Interestingly, measurements reveal that the relaxation of a living cell as it is squeezed between the pipette and a substrate is logarithmic. Such relaxation has been seen in other strongly interacting complex systems such as granular materials, spin-glasses and proteins. The MD methodology can be applied to a wide variety of systems: cell-substrate or cell-cell, and any other systems that can be manipulated with the micropipette like colloidal beads, fibers, microtubules, and aggregates. Furthermore, by scanning a sample it is possible to carry out both friction measurements and force imaging. ■

▮▮▮ **M.-J. Colbert**, **A.N. Raegen**, **C. Fradin** and **K. Dalnoki-Veress**, 'Adhesion and membrane tension of single vesicles and living cells using a micropipette-based technique', *Eur. Phys. J. E* **30**, 117 (2009).

Relativistic Molecular Dynamics in very high Laser Fields

Investigation of photo-molecular processes in intense light fields is currently on the verge a new phase of development. This is due mainly to the recent technological advances made in the generation of high-intensity high-frequency free-electron-laser radiation, and low-frequency pulsed laser radiation exceeding an unprecedented 10^{22} W/cm^2. It has opened up the possibility of controlled induction of Auger-effect, stimulated Koester-Koenig effect, creation of inverted ``hollow-molecules" etc.; hopes are also high for the discovery of hitherto unexpected phenomena occurring, for example, through real or virtual excitation of multi-electron correlation by the radiation fields.



◀ Spin-dependent molecular two-slits interference effect: Self-interference of an ionizing electron initially in a mixture of up and down spin states, in the presence of two atomic centers of a diatomic molecule.

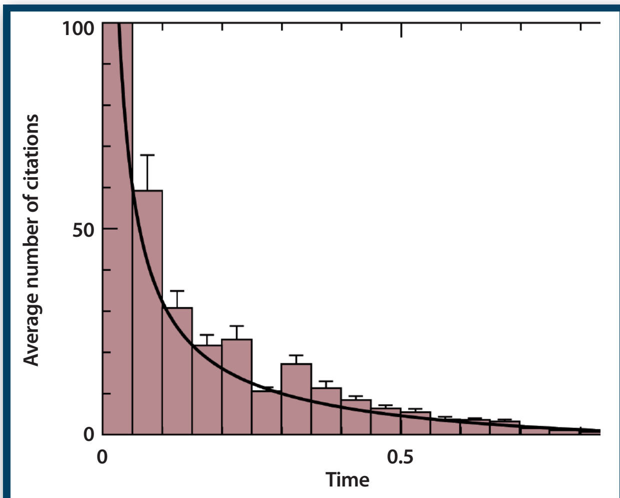
To analyze and interpret the gamut of expected phenomena in the impending experiments, and to explore possible new effects, a non-perturbative relativistic theory of super-intense laser-molecule interaction processes is needed. In the recent paper presented here, a pioneering effort in this direction has been made. The author has presented a relativistic 4-component Dirac theory of photo-molecular ionization process in a radiation field of any polarization, frequency, and intensity. A first application of the theory is made to analyze the ionization dynamics of deep-lying shells of molecules analogous to that of a hydrogen molecular ion. The results show among other things that the dynamics is governed by a relativistic two-slit interference effect that arises from the spin-dependent electron waves emerging from the two nuclear centers of the molecule. It also predicts an asymmetry of up and down spin electron currents that could be controlled by selecting the handedness of the circular polarization of the inducing field. The last effect is expected to be useful, for example, for the dynamic 'molecular imaging' problem, and for the new science of 'spintronics'. ■

▮▮▮ **F.H.M. Faisal**,
'A four-component Dirac theory of ionization of a hydrogen molecular ion in a super-intense laser field', *J. Phys. B: At. Mol. Opt. Phys.* **42**, 171003 (2009)

The first-mover advantage in publications

In the 1970s, Yale University physicist and science historian Derek de Solla Price proposed a simple mathematical model of the citation process for scientific papers in which papers receive new citations in proportion to the number they already have, a kind of "rich get richer" effect now commonly known as "preferential attachment". In the present paper, M. Newman argues that Price's model, if correct, would imply a strong first-mover advantage in publication whereby the first papers appearing in a field should receive enormously more citations than those coming after them, essentially regardless of content. The effect could span orders of magnitude under quite common conditions and would be far larger than would be expected simply because the first papers in a field have been around longer. Newman tests this prediction against empirical citation data from several different fields and finds, in some cases, surprisingly close agreement between theory and observation. Newman suggests that his results could be the basis for a number of further analyses. By dividing out the first-mover effect, for instance, one could create a measure of paper impact that is independent of time of publication and hence could, in theory, predict whether or not recently published papers will subsequently be influential. The method might also be used to distinguish a true new field of science from a research area that is more correctly viewed as a part of a larger field, since the former should show the predicted first-mover effect while the latter should not. ■

▮▮▮ **M. E. J. Newman**,
'The first-mover advantage in scientific publication',
EPL **86**, 68001 (2009)

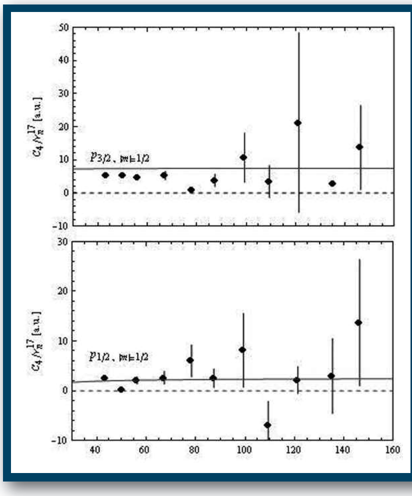


▲ The average number of citations received by physics papers in the field of network theory, as a function of (rescaled) time of publication, measured since the first such papers appeared in the literature. The solid curve is the theoretical prediction and the bars are the observed data.

Hyperpolarizabilities **of Rydberg atoms**

The development of laser instrumentation made highly excited Rydberg states of atoms well accessible already 1970-s. At present the Rydberg atoms have become a useful tool in research and technology. The principal advantage of Rydberg atoms is their high sensitiveness to very weak external fields. Therefore, the Rydberg atoms may be used as highly precise sensors of very low electric fields. In addition, the long-range interaction between Rydberg atoms opens wide horizons for the newest technologies of processing the quantum information.

For the efficient use of Rydberg atoms, the shift and splitting of the energy levels (Stark effect) should be known in detail. The principal characteristics describing the second-order response of the atomic level to a dc electric field are the polarizabilities. In the paper, the scaling equation in powers of the Rydberg-state effective principal quantum number is presented together with the numerical data for every series of states with low angular momentums $l \leq 2$ in helium (both singlet and triplet) and alkali-metal atoms (*Li, Na, K, Rb* and *Cs*).



◄ **ν_n dependences of fourth-order Stark coefficients C_4, divided by ν_n^{17}, in Rydberg $nP_{1/2}$, $nP_{3/2}$ (|m|=1/2) states of *Rb*. Theoretical results of this work: solid lines; experimental result: closed circles (T. Haseyama, K. Kominato, M. shibata *et al.*, *Phyics Letters A* 317, 450 (2003)**

For highly excited Rydberg states the fourth-order Stark effect, described by the hyperpolarizabilities, becomes significant already in rather low electric fields. The hyperpolarizabilities determine also the range of validity of the power series for the Stark effect. In the paper, the scaling equations for hyperpolarizabilities and for the oscillator-strength-distribution moments *S*(-3), which appear in the fourth-order analytical expressions, are also presented. The scaling equations were derived from the numerical calculations in the Fues' model potential approach. The data of the paper may be used to control the behaviour of the Rydberg atoms in dc electric fields. ■

E.Yu. Il'inova, A.A. Kamenski and **V.D. Ovsiannikov**, 'Hyperpolarizabilities of Rydberg states in helium and alkali-metal atoms', *J. Phys. B: At. Mol. Opt. Phys.* **42**, 145004 (2009)

Small surface **wave discharge**

Microwave surface-wave sustained discharges are electrode-less discharges, which have many applications in the new technologies of surface treatments. The electrons in the gas are accelerated by a microwave electric field and after several elastic collisions they get enough energy to excite or to ionize the heavy particles via inelastic collisions. The partially ionized gas becomes a plasma which supports microwave propagation along the surface boundary between the plasma and the surrounding dielectric tube.

The high power microwave generators and the metal wave-guides determine the large dimensions of the currently used plasma sources.

► **Operation of the small surface wave discharge as a plasma jet and a microwave probe.**

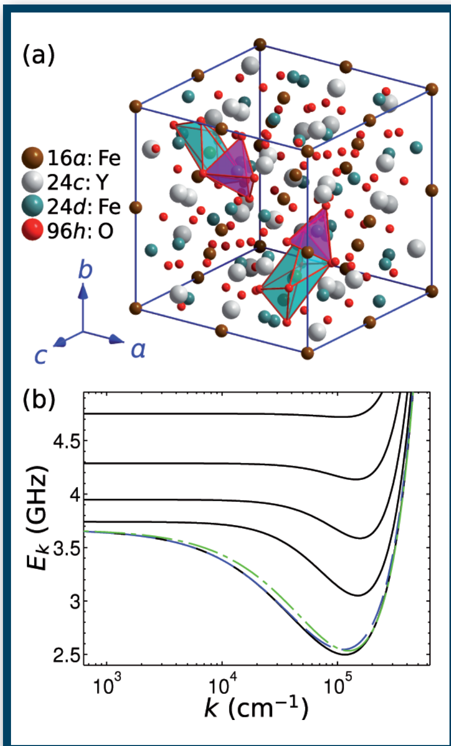
A novel, small discharge sustained in the field of surface wave is developed to work effectively at atmospheric pressure. Microwave power at frequency 2.45 GHz is coupled with the coaxial exciter which has a length of 10 mm. The discharge is self-ignited in a ceramic tube (inner diameter of 1 mm and length of 11 mm) at microwave power levels below 10 W and works in continuous and pulse regimes in argon and argon-helium gas mixture. Discharge column length is controlled by the applied microwave power. The source could operate also as a plasma jet. The resulting plasma is characterized by the high density of the charged particles. The temperature of the electrons is higher than the temperature of the heavy particles. The radiated emission of the argon discharge has a rich spectrum from UV to IR region.

This small plasma source maintains stable plasma columns at atmospheric pressure over a wide range of neutral gas flow and applied power. The qualities of the source are suitable for applications in analytical spectroscopy and plasma coating technologies. ■

Zh. Kiss'ovski, M. Kolev, A. Ivanov, St. Lishev and **I. Koleva**, 'Small surface wave discharge at atmospheric pressure', *J. Phys. D: App. Phys.* **42**, 182004 (2009)

Spin-waves in **Yttrium-iron garnet**

Recently spin-waves in thin films of the ferrimagnetic insulator yttrium-iron garnet (YIG) have been excited via microwave pulses and detected through optical Brillouin light-scattering. Using the fact that the spin-wave (magnon) dispersion in thin films of YIG has a minimum at finite wave-vectors, Demokritov *et al.* (2006) showed that magnons can condense into a strongly correlated coherent state even at room temperature.



◄ **(a)** Elementary cell of YIG with 160 atoms. The spins of the 16 Fe in positions a are coupled anti-ferromagnetically to the spins of the 24 in positions d and cause the ferrimagnetic ordering. **(b)** The lowest modes of the spin-wave spectrum of a thin YIG film exhibit local minima at finite wave vectors. Especially interesting is the lowest mode where large magnon densities can be created by microwave pumping.

The existence of a minimum in the magnon spectrum of YIG is the result of a subtle interplay between finite-size effects of the thin film, the short-range exchange and the long-range dipole-dipole interactions. Although the main features of the magnon spectrum of YIG can be understood within the phenomenological Landau-Lifshitz equation, we have used a microscopic approach based on the usual *1/S*-expansion, a successful tool to understand the quantum excitations in ordered magnets. Combining the *1/S*-expansion with Ewald summation techniques to perform the dipolar sums, we have calculated the magnon-spectrum of experimentally relevant thin YIG films. Our approach provides a straightforward method to determine the interactions between magnons, which is a starting point for further investigations on the non-equilibrium behaviour of the magnon gas in YIG. ■

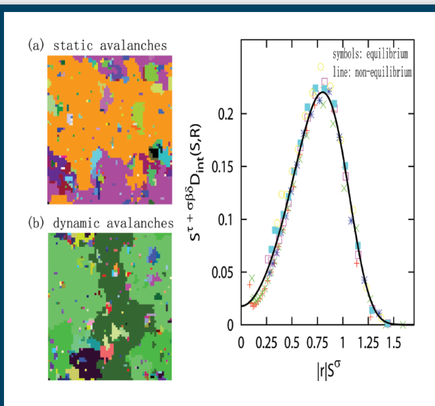
▮▮▮ **A. Kreisel**, **F. Sauli**, **L. Bartosch** and **P. Kopietz**, 'Microscopic spin-wave theory for yttrium-iron garnet films', *Eur. Phys. J. B* **71**, 59 (2009)

Similar scaling in and out **of equilibrium**

Equilibrium systems are believed to be completely different from non-equilibrium ones simply because the underlying physics is so different. However, we have demonstrated that the random-field Ising model (RFIM), which is a prototypical model for magnets with quenched disorder, exhibits surprisingly similar scaling behaviour in equilibrium and out of equilibrium. In particular, the static (equilibrium) and dynamic (non-equilibrium) avalanches of RFIM behave the same in the statistical sense: They have the same size distribution and the same spatial structure.

Avalanche behaviour in diverse dynamical systems has been extensively studied in the past decade: There are often a large number of metastable states. When pushed by an external driving field, those systems shift from one metastable state to another, responding with collective behaviour in the form of avalanches. A dynamic avalanche is just the rearrangement of the system configuration, which connects two different metastable states at two slightly different external fields. So far, avalanche behaviour in equilibrium systems (static avalanche) was rarely studied due to computational complexity. With a static avalanche we refer to a configuration rearrangement connecting two different neighbouring ground *states* at two slightly different external fields.

► **(left)** Cross sections of cubic lattices showing all the avalanches occurring during the magnetization processes. **(right)** Scaling collapse of avalanche size distributions.

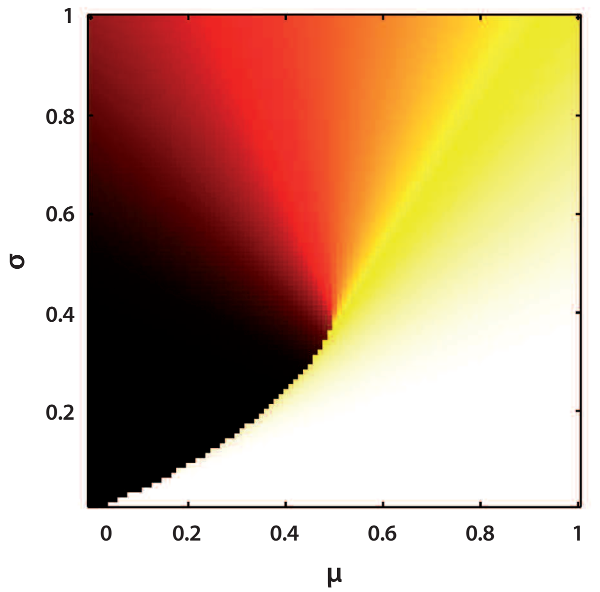


Comparing the static and dynamic avalanches in Gaussian RFIM at zero-temperature, we found that they share the same universal quantities, *e.g.* critical exponents and scaling functions associated with the size distribution, fractal dimensions and anisotropy measures associated with the spatial structure. The critical properties of equilibrium and non-equilibrium RFIM are then much more generally applicable than previously assumed. In this case, systems far from equilibrium may be used to predict equilibrium critical behaviour, and vice versa. ■

▮▮▮ **Y. Liu** and **K. A. Dahmen**, 'Random-field Ising model in and out of equilibrium', *EPL* **86** 56003 (2009).

Systemic Risk beyond **financial systems**

Systemic Risk denotes the risk that a whole system, consisting of many interacting elements, fails.



▲ X is coded in colour (where white means 0 and black means 1). μ is a measure of the average susceptibility to fail, with a standard deviation σ. The first order phase transition between a globally healthy and a globally failed state is clearly observable.

This is not only a problem in financial systems but also in social systems (*e.g.*, spreading of an epidemic disease), in technical systems (*e.g.*, blackout of power grids) or in materials (*e.g.*, rupture of a bundle of fibres). These systems may exhibit a switch to collective failure, which is reminiscent of phase transitions in physical systems. As in many problems in statistical physics, the question is how such a macroscopic state may emerge from local interactions of the subunits, given some specific boundary conditions. The fraction X of failed elements can be regarded as a measure of systemic risk. How can one predict the value of X over time or asymptotically? In a recent paper, the authors were able to solve this question by developing a general framework for models of cascade and contagion processes on networks. They could identify three model classes, which differ in their microscopic interaction mechanism and cover most phenomena of collective breakdown. For each model class, a phase diagram (see Fig) was derived to show the critical conditions where small changes in the initial conditions lead to global failure. ■

J. Lorenz, **S. Battiston** and **F. Schweitzer**,
'Systemic risk in a unifying framework for cascading processes on networks', *Eur. Phys. J. B* **71**, 441 (2009)

Antiproton-nucleus **annihilation**

Electromagnetic form factors tell us about the electric charge distribution and magnetic moment inside the nucleon and are functions of t, the square of the momentum transfer, which mathematically can be of either sign. They have been measured in the space-like region (t<0) for fifty years by elastic electron-nucleon scattering, while in the time-like region they are measured in proton-antiproton annihilation into electron-positron pairs or its inverse reaction providing information on nucleon-antinucleon interaction. An interesting exploration would be in the under-threshold region, requiring the proton or the antiproton to be off-mass-shell, where among other things quasi-nuclear bound states are recurrently predicted to exist. The present work relies on the fact that a nucleus provides nucleons with various degrees of off-shellness. This idea explored the 1980's in the case of deuteron, and almost stopped antiprotons, is now revived in view of future experiments with relatively high-energy beams.
An exploratory study of this reaction has been undertaken in the context of the PANDA detector at FAIR, in Darmstadt, Germany. While noting that with energetic antiprotons the relevant under-threshold region is very hard to reach, and that one has to fight against a large background, the feasibility relies on the expected detector performances. ■

H. Fonvieille and **V. Karmanov**,
'Antiproton-nucleus annihilation and time-like form factors of the proton, *Eur. Phys. J. A* **42**, 287 (2009))

Calls & winter school

Gerhard Ertl Young Investigator Award
Prof. Martin Aeschlimann invites to apply for the Gerhard Ertl Young Investigator Award for Excellent Research in Surface Science, which will be awarded from now by the DPG Surface Science Division at the Spring Conference.

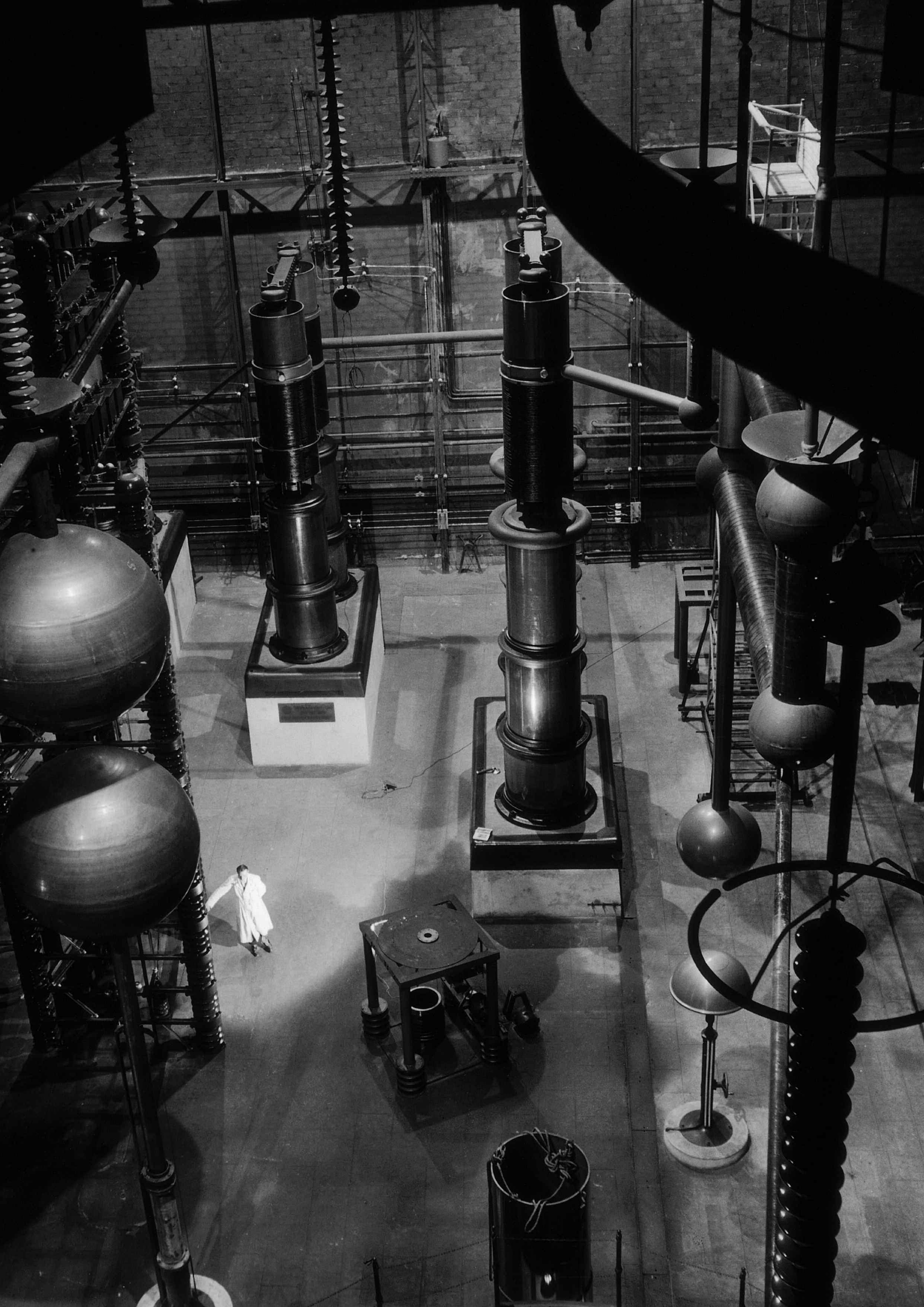
For details, ask M. Aeschlimann: ma@physik.uni-kl.de.

Max Auwärter Award 2010
O. Univ. Prof. Dr. Falko P. Netzer invites less than 35 year-old scientists in surface physics, surface chemistry, or organic and inorganic thin films to apply for the Max Auwärter award 2010.

For details, ask F. Netzer, falko.netzer@uni-graz.at.

46th Winter School of Theoretical Physics
The "46th Winter School of Theoretical Physics" will be held from 8-13 February 2010 at Ladek Zdroj, Poland.

For details, ask R. Olkiewwicz: rolek@ift.uni.wroc.pl



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FRÉDÉRIC JOLIOT-CURIE AND THE FIRST FRENCH ATOMIC REACTOR

Half a century ago Frédéric Joliot (1900-1958) passed away. With his wife, Irène Joliot-Curie, he had discovered artificial radioactivity in 1934, for which they were awarded the Nobel prize in chemistry in 1935. This led ultimately to the start-up, under his leadership, of the first French nuclear reactor ZOÉ, in 1948.

Frédéric Joliot was born in Paris on March 19th, 1900. At the top of his year when completing his engineering school, the *École municipale de physique et chimie industrielles*, he is introduced by Paul Langevin, its director for education, to Marie Curie who immediately recruits him as personal assistant at her laboratory at the *Institut du Radium* (Radium Institute). Irène Curie, daughter of Marie and Pierre, is in charge of showing him around the laboratory. The two young people will get married in 1926 and will jointly undertake a series of experiments in the field of radioactivity.

Discovery of artificial radioactivity

In 1930, in Berlin, W. Bothe and H. Becker note that the bombardment of beryllium with alpha particles produces a very penetrating non identified radiation. In Paris, Frédéric and Irène produce small very intense sources of polonium, an alpha emitter. At the beginning of 1932, they observe that the penetrating radiation is able to eject recoil protons out of sheets of hydrogenated substances. This will be the starting point for James Chadwick who, one month later, at Cambridge, discovers that the unknown radiation consists of "neutrons".

Following up their experiments, Frédéric and Irène discover, in January 1934, "artificial radioactivity", that is the production of radioactive isotopes of stable elements by nuclear reactions in other elements (for instance radioactive phosphorus formed in aluminum). This is a remarkable generalization of natural radioactivity with multiple applications, in particular in biology. This discovery brought the two young scientists the Nobel Prize in chemistry of 1935. On their return from Stockholm, at a banquet given in their honour, Paul Langevin proposes to call both "Joliot-Curie" from then on.

◄ The "laboratoire de synthèse atomique d'Ivry", summer 1942

Immediately, in Rome, Enrico Fermi and his team decide to produce, if possible, radioactive isotopes of all available chemical elements, using neutrons, which are able to penetrate in the heaviest nuclei. They observe in uranium irradiated by neutrons what they believe to be isotopes of "transuranic" elements, nuclei heavier than uranium. The torch is handed over to Otto Hahn, Lise Meitner and Fritz Strassmann in Berlin; in their publications these scientists indicate that they had identified several series of transuranic isotopes. Early 1938 in Paris, Irène Joliot-Curie and Paul Savitch open a new way for studying this problem.

Fission, chain reaction and international background

In July 1938, following the *Anschluss*, Lise Meitner, having Austrian nationality and Jewish origin, is forced to flee from Germany, taking refuge in Sweden. Hahn and Strassmann resume their chemical separations in order to examine with still more care whether some of the transuranic isotopes would not actually be isotopes of radium. Just before Christmas of 1938, to their great surprise, they

▼ **FIG. 1:** Irène and Frédéric Joliot-Curie in their laboratory at the Radium Institute.

▲ **FIG. 2:** From left to right: F. Joliot, H. Halban and L. Kowarski (adjusting a pulse amplifier) at the laboratoire de chimie nucléaire of the Collège de France.

▼ **FIG. 3:** F. Joliot (with raincoat) and L. Kowarski (to the right) in front of the blockhouses of the Châtillon fort in 1946.

dicover that these radionuclides are not isotopes of radium but isotopes of barium, a much lighter element; uranium nuclei would thus have "burst" under the action of the bombarding neutrons. Their results are published early January 1939. Alerted by Otto Hahn, Lise Meitner, with her nephew Otto Frisch, provide a physical explanation of the phenomenon, to which Frisch will give the name of "fission"; they publish this explanation in February.

Professor at the *Collège de France* in Paris, Joliot immediately seizes this problem. He realizes, like a few of his colleagues in other countries, that fission must release a considerable amount of energy. This observation leads him at once to an experiment on the recoil nuclei, providing a physical proof of fission (end of January, 1939). A cloud chamber picture provides additional confirmation. He thinks that fission must be accompanied by new neutrons, which would thus open the possibility of a chain reaction. He then forms a team with Hans Halban and Lew Kowarski in order to check experimentally that new neutrons are actually emitted, and, after that, to measure their energy and establish their number. The results which they obtain are very encouraging.

The team of the Collège de France is in competition with a team at Columbia University in New York, led by Fermi and joined by Leo Szilard. The French team is in general ahead by one to three weeks; Francis Perrin is asked to join in order to compute the dimensions of an energy producing device. On May 1st, 2nd and 3rd, the team takes out three patents on behalf of the *Caisse nationale de la Recherche scientifique* (father of the present CNRS). Immediately afterwards F. Joliot travels to Brussels to propose an industrial collaboration to the *Union minière du Haut-Katanga*, a company which holds the most important uranium mines. A memorandum of understanding is signed and a draft agreement is prepared. The Union minière places a total of 8 tons of uranium oxide at the disposal of the French team, which carries on its work at the Laboratory of atomic synthesis at Ivry, in the southern suburbs of Paris. In a few weeks, F. Joliot has shifted from basic science to applied science. In the United States, N. Bohr and J.A. Wheeler show that uranium-235, the less abundant isotope of natural uranium, is responsible for the fission by slow neutrons.

The war breaks out on September 1st, 1939. Work goes on, but the results are no longer published; a sealed letter is deposited at the Academy of sciences. Frédéric Joliot is received by Raoul Dautry, the new Minister for armament, and explains to him the aims of the ongoing work. Slow neutrons are more efficient for producing fission; the team uses a hydrogenous medium ("moderator") for slowing down the neutrons. However they realize that, in order to obtain a divergent chain reaction, moderator and uranium must be separated and form a heterogeneous device. They also realize that ordinary hydrogen absorbs neutrons too efficiently and therefore want to use deuterium as a moderator. Consequently, they must obtain heavy water which, at that time, is only prepared at Rjukan in Norway. On the basis of a report by Joliot, Dautry decides to send lieutenant Jacques Allier, as head of a commando, on a secret mission to Norway to get the precious product. The operation unfolds successfully at the beginning of March 1940, bringing 167 liters of heavy water to France.

Two new patents are taken out on April 30th and May 1st, 1940. However, soon after that the German invasion of France begins. Halban, Kowarski, the heavy water and a large part of the equipment are withdrawn to Clermont-Ferrand, joined by F. Joliot just before the Wehrmacht marches into Paris. The situation has become dramatic. The three physicists take the heavy water to Bordeaux. At Joliot's request, Halban and Kowarski, with an official travel warrant, embark for England on June 17th, on board the "Broompark", carrying the stock of heavy water and the documents corresponding to the last results obtained by the team. F. Joliot decides to stay in France. The uranium, transported to Morocco, is hidden in a closed-down mine gallery during the entire war. Upon arrival in London, Halban and Kowarski draw up the summary and the conclusions of the last work of the team; they end with the following sentence : *"Two ways are recommended for the production of energy : the method of slow neutrons with a little enrichment in uranium-235; or the hope that the capture of neutrons by uranium-238 leads after all to a new fissionable nucleus [1])."*

Frédéric Joliot, having returned to Paris, faces up to the situation. He finds his laboratory at the Collège de France occupied by the Germans, but under the authority of a friendly physicist, Wolfgang Gentner, an "elder" of the Institut du Radium. Gentner will protect him efficaciously when Joliot gets actively involved in the Resistance movement. The physicist undertakes research in collaboration with biologists on the use of radioactive isotopes in biology.

After the war : the Department of atomic energy (CEA) and ZOÉ

At the Liberation, in August 1944, Joliot is appointed Director general of the National Center for Scientific Research (CNRS). He gradually learns about what has been achieved in the United States during the war, and in particular the starting up of the first atomic pile (nuclear reactor) in Chicago, under the leadership of Fermi, in December 1942. Joliot has two conversations with General de Gaulle, president of the provisional government: in November 1944, and, together with Pierre Auger, in May 1945. The idea of a French organization especially devoted to atomic energy (nuclear energy) is dawning. After the atomic bombs on Hiroshima and Nagasaki in August 1945, de Gaulle has an 'ordinance' adopted in October establishing the CEA (Commissariat à l'énergie atomique); the text had been prepared by F. Joliot and R. Dautry. On January 3rd 1946, de Gaulle appoints Frédéric Joliot to be "Haut-commissaire" and Raoul Dautry to be general Administrator of the CEA.

F. Joliot immediately launches a systematic search for uranium ore in France. Three years afterwards, in February 1949, he was to describe the programme of the new organization in the following way,: *"We started almost from scratch as far as equipment was concerned, and we had to create everything; but the special ordinance which established the CEA had been taken with a view to make our task easier. We have immediately foreseen three stages in the development of atomic energy, and the first of these comprised the construction of a heavy water uranium pile, of low power, together with all the subsidiary constructions this included."*

Under the enthusiastic impetus of Frédéric Joliot and the direction of Lew Kowarski back from Canada, the pile ZOÉ (for Zero power, uranium Oxyde and heavy Water) is built at the fort of Châtillon in Fontenay-aux-Roses. For that achievement the CEA has at its disposal the results obtained by the team of the Collège de France in 1939-1940, the uranium brought back from Morocco, the agreements concluded with Norway for heavy water, the knowledge brought by the French scientists returning from Canada (Kowarski, Goldschmidt, Guéron and Auger) and parts of the Smyth report publicized by the American authorities as early as August 1945 (*Review of Modern Physics*, October 1945). The work is proceeding fast. The uranium is processed at the Le Bouchet factory, south of Paris. On December 15th of 1948, ZOÉ, the first French atomic reactor, begins operating. It will supply artificial radioactive isotopes for biological applications, allow the training of technicians and the development of materials necessary for the construction of medium power reactors. Its external installation has been preserved and one can visit it by appointment.■

▼ FIG. 4: Frédéric Joliot (on the left) and Lew Kowarski (on the right) accompanying the President of the Republic, Vincent Auriol (center), at the inauguration of ZOÉ in December 1948.

About the author

Pierre Radvanyi is a nuclear physicist, active in history of science; he is honorary director of research at the CNRS. After a Ph.D., directed by F. Joliot-Curie, on radioactivity by electron capture at the Collège de France, he worked with the Orsay synchrocyclotron, the Saclay linear electron accelerator and the Saturne synchrotron. He has been deputy director of *Laboratoire national Saturne* (1978-1985).

The 1st version of this article has been published in "Reflets de la physique" 11, 17 (2008). Figures 1-4 are under copyright "Association Curie et Joliot-Curie".

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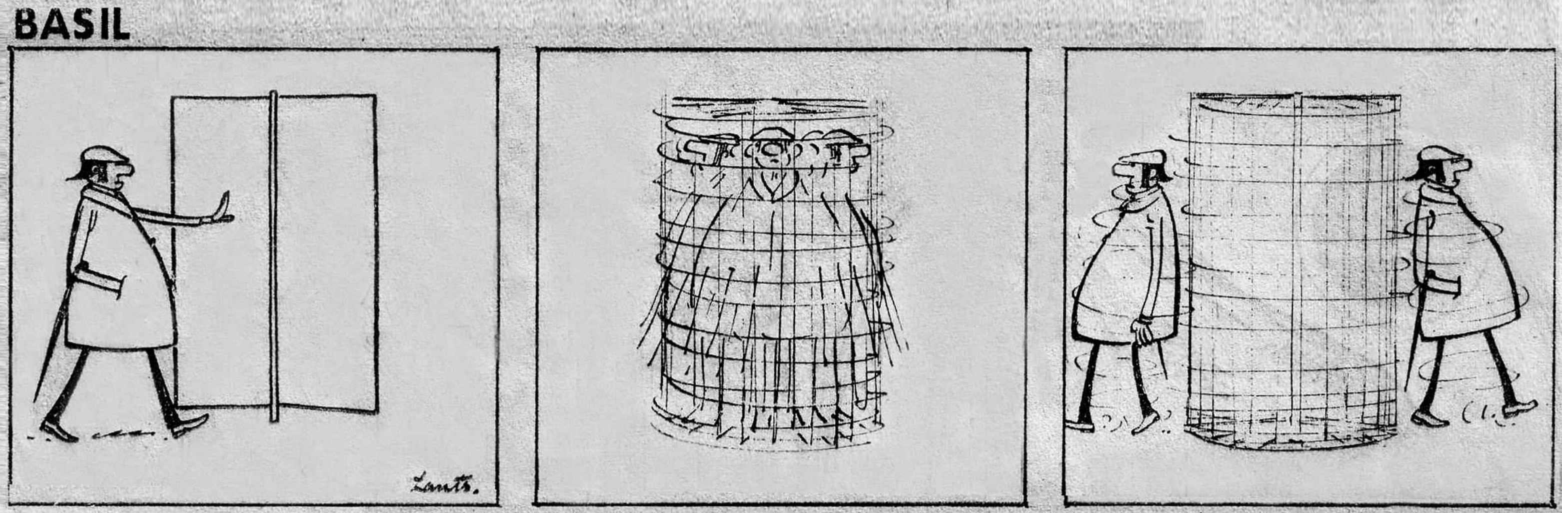
note

[1] This will actually be plutonium 239, discovered in Berkeley in 1940/1941.



▲ Acknowledgment to Gerry Lants, Australian cartoonist © Herald and Weekly Times, Melbourne, Australia.

NEUTRON INTERFEROMETRY:

A TALE OF THREE CONTINENTS

* **Tony Klein** * School of Physics, The University of Melbourne, Parkville, Victoria 3010, Australia * **DOI: 10.1051/epn/2009802**

In the 35 years since its first implementation, neutron interferometry has produced some fascinating demonstrations of quantum mechanics in action, has allowed the testing of a number of interesting quantum mechanical propositions and has allowed the precise measurement of physical quantities of vital importance in condensed matter physics.

This was one of the conclusions that emerged from the Vienna Symposium on the Foundations of Modern Physics held in June this year. Organised by Anton Zeilinger, ably assisted by Markus Aspelmeyer and the staff of the Institute of Quantum Optics and Quantum Information (IQOQI) this Symposium, the 2nd in the series, also served as a Festschrift for Helmut Rauch and Danny Greenberger, noted experimental and theoretical luminaries in the field.

In particular, it was Helmut Rauch who, together with Wolfgang Treimer and Ulrich Bonse, was first to demonstrate the first Single Crystal Neutron Interferometer in 1974 [1]. Closely analogous to a Mach-Zehnder Interferometer in classical optics, these wonderful devices are carved out of a monolithic piece of highly perfect single crystal of silicon, of the kind used in the semiconductor electronics industry. A photograph and a schematic are shown in fig 1.

Three parallel slabs of silicon, connected by a base, contain perfectly aligned planes of atoms, which, by virtue of Bragg Diffraction, coherently split a beam of monochromatic neutrons, whose wavelengths are comparable in magnitude to the lattice spacing of the silicon crystal. Furthermore, the silicon is almost completely transparent to neutrons – so that absorption is essentially negligible. Thus, the first slab acts as a beam splitter, with a transmitted and a diffracted beam emerging from it. Both these beams continue to the second slab at which Bragg diffraction occurs once again. Ignoring the transmitted beams (which escape from the system), the two diffracted beams continue on their way to the third, equidistant slab, where they recombine in a way similar to the first beam splitter. Although we have ignored the complex interplay of the beams inside the crystal slabs, which can only be calculated by using the dynamical theory of diffraction, by some miracle the three slabs of the silicon crystal act like the half-silvered mirrors in the optical interferometer.

Several centimetres separate the internal beams, but there is only one neutron inside the device at any given time. However, in the usual quantum mechanical prescription, it is impossible to tell which of the paths the neutron has taken – it travels along both paths at the one time!

The relative phases of the beams are influenced by inserting material slabs of different thicknesses inside the interferometer – in practice by tilting the one slab of material so that the beams traverse different thicknesses – and thus the interaction of the neutrons with the nuclei of the materials can be measured to a very high degree of precision. In effect this is a measurement of the refractive index of the material for neutrons that, in turn, depends on the scattering lengths of its constituent nuclei – important data in neutron diffraction crystallography. Rauch's and other research groups have performed a large number of such measurements over the years, using powerful neutron beams at the High Flux Reactor of the Institut Laue – Langevin (ILL) in Grenoble.

But no sooner was such a neutron interferometer constructed in Europe, a very similar one was produced in the USA, and the way was open for a large number of beautiful and fundamental experiments, each of them testing some aspect of quantum mechanics and exploring the fundamentally analogous behaviour of particles and waves, in fact doing macroscopic wave-optical experiments with neutrons. Shortly after the demonstration of the first neutron interferometer by Rauch and his colleagues at the small research reactor of the Atominstitut in Vienna, Sam Werner and his colleagues at the Ford Motor Company Research Labs in Michigan (and later at Purdue University), designed and built similar devices and performed spectacular experiments with them. The competition was on!

Instead of just inserting material objects inside the interferometers one of the first experiments of the American group famously demonstrated the effect of the earth's gravity on the neutron beams inside the interferometer. In what has become known as the COW experiment [2] (after Colella, Overhauser and Werner) the interferometer was tilted about a horizontal axis parallel to the incoming beam. In this way, the two diffracted beams inside the interferometer become separated by a vertical distance and thus experience different gravitational potentials, by traveling at different heights above the earth's surface. The resultant phase differences become apparent in an interferogram plotted as a function of beam height difference. The measurement may be expressed using a formula that simultaneously involves Planck's constant h, and the gravitational constant g, the first macroscopic manifestation of a quantum-mechanical effect due to gravity.

The next spectacular experiment was also one in which a field, instead of a material object, was to act on the neutrons – this time a magnetic field. But by then a third research group had entered the competition – this time from Australia. My late colleague Geoffrey Opat from the University of Melbourne and I, came across a paper by Aharonov and Susskind [3] proposing a gedanken experiment with electrons to demonstrate the peculiar behaviour of fermions, *i.e.*, particles with half-integral spin, when rotated by 360° about any axis: they do not return to their original state, like any macroscopic object, but develop a minus sign in their wave function. Up until then considered as merely a mathematical artifact, this minus sign is in fact crucial in explaining the Pauli exclusion principle that is responsible for the stability of ordinary matter. (The connection is explained in a side panel.)

To perform the rotation required in an experimental verification, a magnetic field is made to act on the intrinsic magnetic moment of the fermions, causing them to precess. The phase shift caused by the rotation can be made apparent in an interference situation; the minus sign, *i.e.* the 180° phase shift caused by an odd number of 360° rotations, will lead to destructive interference.

We immediately realised that neutrons would be needed to demonstrate the effect – electrons would be swept aside by the Lorentz force - and so did Rauch's group in Vienna and so did Sam Werner, who by this time had moved to the University of Missouri. As a matter of fact, a paper by Herbert Bernstein [4] published almost simultaneously with the Aharonov – Susskind paper, explicitly suggested neutron interferometry to demonstrate the effect, several years before the first crystal interferometer was built.

That was the case for the Melbourne group too – we planned an interference experiment with neutrons in 1974 before we heard about the crystal interferometer, which in any case, we didn't have. Our experiment was based on interference by division of the wavefront, analogous to Young's two-slit experiment in classical optics. We proposed to diffract slow neutrons around a magnetic domain wall in a thin crystalline foil of iron alloy with the right properties. Having the right thickness would allow the neutrons to precess in the internal magnetic field inside the iron foil, so that the total precession angle would give an integral number of times 360°. For an odd number of revolutions, destructive interference should occur between the parts of the neutron wavefunction that traversed oppositely directed magnetic fields.

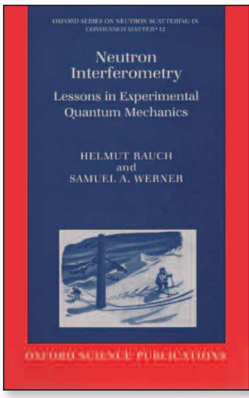
ILL accepted this proposal in 1974 and we published it in1975 [5]. But by the time I arrived to perform the experiment, in September 1975, I found to my consternation that the corresponding experiment had already been done – by the Rauch group (using an electromagnet inside a crystal interferometer), as well as by the Werner group (using a permanent magnet). Their results, verifying this strange property of fermions, were published simultaneously in Physics Letters [6] and Physical Review Letters [7], in October 1975. We lost the competition for priority, but we went ahead and did our version of the experiment anyway – because it used a significantly different method. Our results, which also verified the theoretical prediction, ended up being published in 1976 [8].

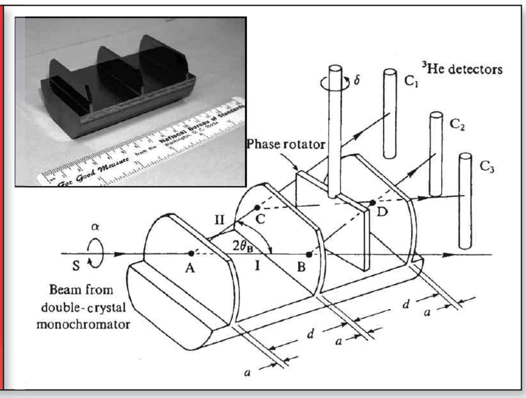
However, what had started out as a competition between the three research groups on three continents turned into something completely different. Catalysed by the first conference on neutron interferometry, held at ILL in 1980, co-operative experiments followed for the next 20-odd years, with various combinations of participants.

The European and Australian groups co-operated on a series of neutron-optical experiments in 1979, including interferometry, and demonstrated the effect of the motion of materials inside a neutron interferometer – analogous to the famous experiments of Fizeau in classical optics [9].

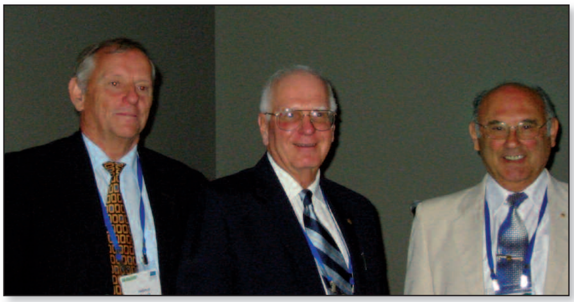
▼ FIG. 1: Schematic of a perfect crystal neutron interferometer. The output beams are counted in detectors C1 and C2 while C3 serves as a monitor of the total flux. The inset is an actual photograph of the monolithic silicon crystal device.

◄ FIG. 2: Cover of the monograph by Rauch and Werner (Oxford University Press, 2000). It contains details of 40 experiments and 1000 references. The picture is the famous New Yorker cartoon by Charles Addams that typifies the quantum mechanical behaviour of particles.





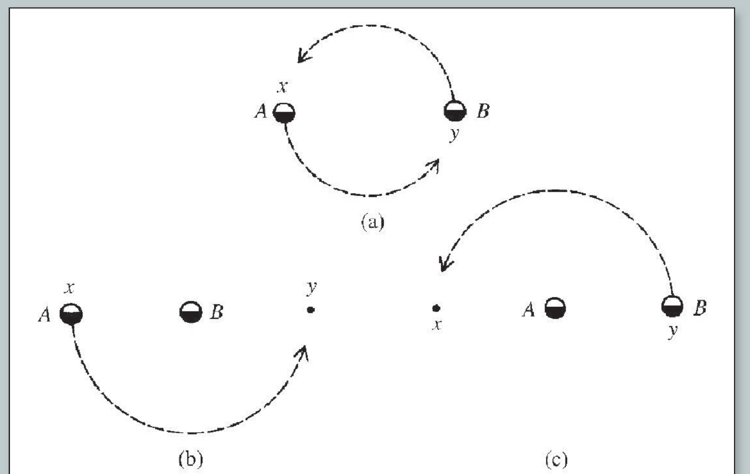
Meanwhile, the American group demonstrated the effect of the earth's rotation on the phase shift of neutrons – analogous to the experiments of Michelson and Gale in classical optics and only about 2% of the magnitude of their earlier gravity experiment. There followed a series of experimental collaborations between the Australians and the Americans in the 1980's further exploring the effects of the motion of matter on the phase shift of neutrons, demonstrating a null effect that depends on the velocity-independence of the neutron-nucleus interactions [10].
Later collaborations, in the 1990s explored a number of topological effects, analogous to the famous Aharonov - Bohm propositions in electrodynamics. The analogous effects for neutral particles, named after Aharonov and Casher, showed that moving neutrons can feel the effects of an electric field, in spite of being electrically neutral, because of their magnetic moment [11]. Furthermore, it became possible to demonstrate an analog of the so-called scalar Aharonov - Bohm effect that had hitherto not been observed with electrons [12]. The role of neutron interferometry in observing such geometrical and topological phases was reviewed in two recent conferences celebrating Yakir Aharonov and Michael Berry on the occasion of the 50th and 25th anniversaries of their discoveries. [13]
An unintended but felicitous outcome of the Australian – American collaboration was that my research student Bill Hamilton ended up marrying Sam Werner's research student Mohana Yethiraj; both of them are now gainfully employed at the Australian research reactor OPAL after having been research scientists at Los Alamos and Oak Ridge National Laboratories for many years.
The culmination of the European – American collaboration was the publication of a very interesting textbook on neutron interferometry, (Fig2 .) in which the experiments that I described are fully elaborated along with many others and which, incidentally, contains all the references to the original publications. As quantum-mechanical playgrounds, neutron interferometers have thrown much light on the arcane mysteries of particles-acting-like-waves, over and above their role in precise measurements and experimental tests. The main protagonists (Fig.3), now happily retired, are proud of their achievements! ■



▲ **FIG. 3: (Left to Right) The European (Rauch), American (Werner) and Australian (Klein) Collaborators.**

The Pauli principle explained

Feynman showed in an article entitled "The reason for antiparticles"[1] that the exchange of two particles (a) corresponds to each being rotated by 180° (b) and (c) *i.e.* 360° of relative rotation. If a fermion (*e.g.* electron, proton or neutron) develops a minus sign in the wavefunction when rotated by 360° then two identical particles in the same spin state cannot occupy the same position in space because they would interfere destructively if exchanged. Hence the Pauli Exclusion Principle! This "hand-waving" argument was put on a more solid mathematical footing by Michael Berry and Jonathan Robbins [2].



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About the author

Professor Emeritus **Tony Klein** held a Personal Chair in Physics in The University of Melbourne until his retirement in 1998. He served as President of the Australian Institute of Physics (1990 – 91); Head of the School of Physics (1986 – 95); was elected a Fellow of the Australian Academy of Science in 1994 and was appointed a Member of the Order of Australia in 1999. He has published extensively in experimental physics, particularly about neutron optics.

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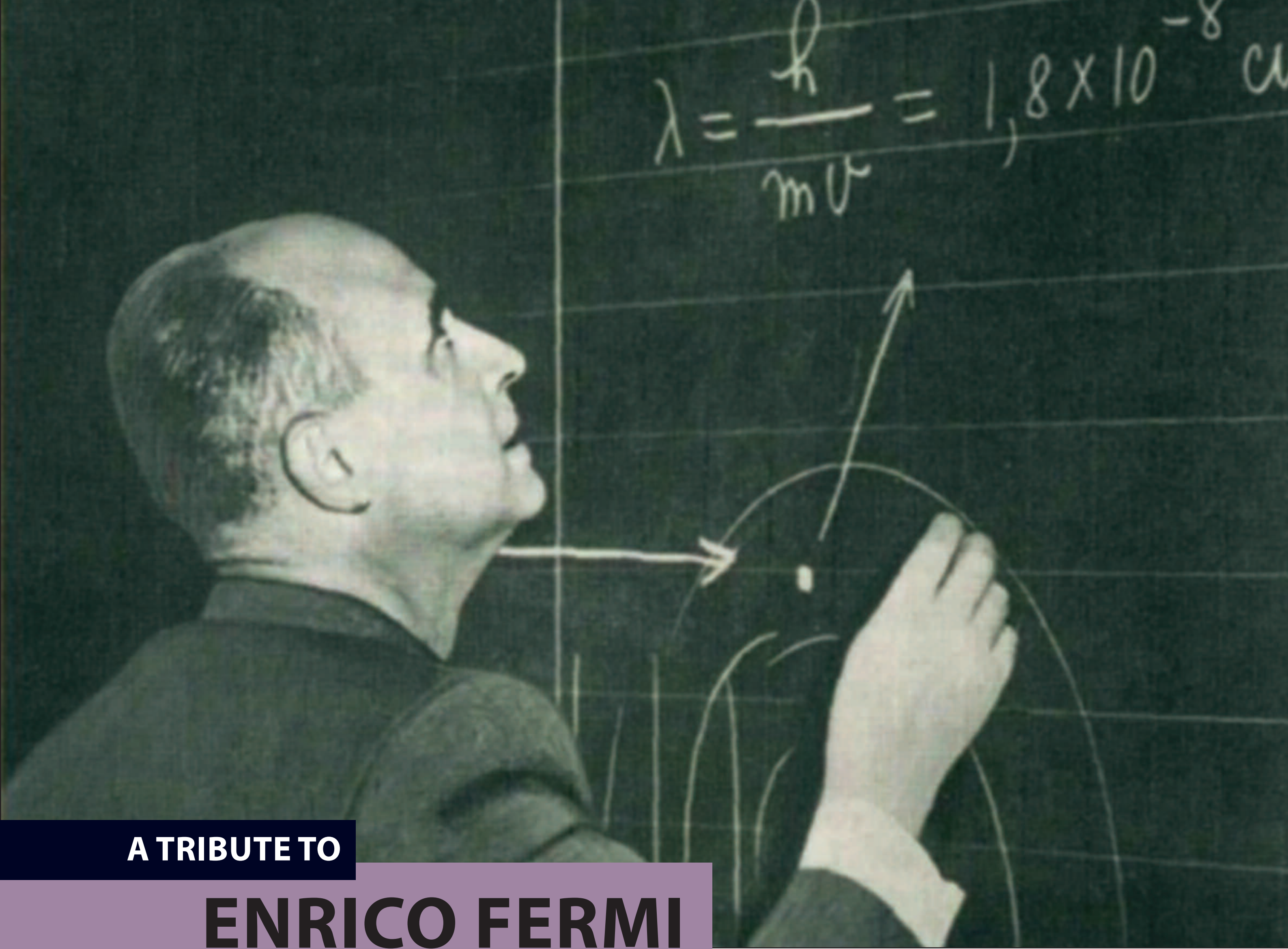


A TRIBUTE TO

ENRICO FERMI

⁕ **Henk Kubbinga** ⁕ University of Groningen (The Netherlands) ⁕ **DOI: 10.1051/epn/2009803**

In the history of physics, Italy has a place of its own. The hightimes of Galileo and Torricelli were followed by those of Galvani and Volta. But not much happened after 1830. Early in the 20th century, though, the spirit of Galileo seemed to be reincarnated in Enrico Fermi (1901-1954).

As a youngster, Fermi attended the public schools of Rome, learned Latin and Greek, and had no trouble in reciting poems [1]. After the baccalaureat he enrolled at the Scuola Normale Superiore, at Pisa, to study mathematics and the language of science, *i.e.* German. The charming lad soon taught his teachers: as a second year's student he lectured on the quantum theory and the Bohr-Sommerfeld atom. Fermi's first post-doc trip abroad was to Göttingen, the contemporary Mecca of theoretical physics. There he worked with Max Born and the latter's students Werner Heisenberg and Pascual Jordan, and published on ergodicity and the adiabatic principle. These papers got translated into German and were noticed by Paul Ehrenfest, the renowned specialist in the field. As a result of a first contact, through George Uhlenbeck, Fermi visited Leiden in September-December 1924 and made the acquaintance of Lorentz, Einstein, Kronig and Goudsmit. At the time the quantization of a 'gas' of equal particles had his particular attention. In 1926 this research gave way to his first major contribution to theoretical physics; it was on the 'Quantization of the ideal monoatomic gas'. The leading idea was to treat the translation of molecules between the parallel walls of a container as a periodic, and therefore quantizable, phenomenon. Instead of the container Fermi, next, posited a radial potential field around a central point – say, the origin of a Cartesian system of axes –, much like the Bohr-Sommerfeld atom. The monoatomic molecules were said to behave like harmonic oscillators of frequency $s_i\nu$ and to be subject to quantum numbers similar to those of the electrons, here s_1, s_2 and s_3, for the three axes, with $s_i = s_1 + s_2 + s_3$. The total energy w of one such atom will thus be $s_ih\nu$. Apparently, an energy equal to 0 may only be realized in one way, an energy of $1h\nu$ in three ways, etc. So the position of lowest energy would only be open to one atom, the second lowest to three, etc., the degeneracy increasing with increasing number of atoms s. At T = 0 the gas would feature 1 atom with energy 0, three with energy $1h\nu$, etc. The 3D-space around the center apparently corresponds to a lattice of cells of volume h^3, each cell ready to contain one atom. By taking, instead of s_1, s_2 and s_3, the three atomic quantum numbers, each with its own value scale, the same logic could be applied to the electrons in the Coulomb field of an atom's nucleus. Here are, of course, the roots of quantum electrodynamics.

Bèta-decay; neutrinos and neutrons

The research on radioactivity, particularly at Cambridge, Vienna, Paris and Berlin, had revealed that α-particles of a particular source had a characteristic energy: their traces in the Wilson-chamber were of uniform length. By contrast, β-particles, supposed to pre-exist as electrons in the nuclei, were expelled with energies varying up to a certain maximum. Pauli had suggested, in 1930, the simultaneous escape of tiny neutral particles in order to maintain energy conservation. It concerned particles like Rutherford's neutrons but light as the electrons, endowed with an energy range that complemented the one of those electrons and for the rest unable to leave traces in the Wilson-chamber. Fermi c.s. became involved simply by organizing a state-of-the-art conference in Rome, in October 1931. The next year was rich in new finds abroad: from Urey's deuteron (January) through Chadwick's neutron (February) to Anderson's positron (August). In the autumn of 1932 Fermi c.s. definitely started to focus on nuclear physics. Still without a programme, new instruments were designed, built and tested: a Wilson chamber, like Lise Meitner's, a gamma-ray single Bi-crystal spectrometer, an ionization chamber, etc. As it happened 'The structure and properties of atomic nuclei' became the theme of the next Solvay congress, that of October 1933; Fermi was among the key-notes. About this time Fermi himself elaborated on the precise nature of bèta-decay in a paper, that would become a classic in the field. The central idea was that electrons do not exist as such in the nucleus, but are produced in much the same way as photons during the decay of activated atomic states according to radiation theory. The difference between a proton and a neutron, then, is nothing but a difference in quantum states of one and the same nucleon: β-particles (and neutrinos) only exist between emission and absorption. Fields had to be quantized, such was the message. Eventual γ-radiation could be attributed to transitions between nuclear isomers.

▼ **FIG. 1:** Enrico Fermi, Werner Heisenberg and Wolfgang Pauli at the Volta centennial at Lake Como (March 1927). The photo was made by Franco Rasetti (courtesy of Emilio Segrè Visual Archives of the American Institute of Physics).

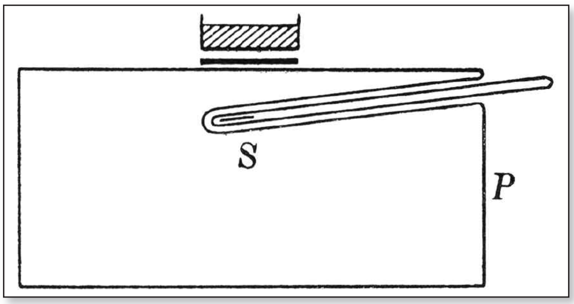
When we may believe a newly (2004!) retraced lab notebook, it was March 1934 when Fermi planned experiments to bombard heavy elements with Chadwick's neutrons in order to test his own new theory of β-decay [2]. The principal piece was a steady neutron source, also of their own device. It was a radon-beryllium combination, the radon (halflife 3,8 days) stemming from Italy's national stock of radium. In a small glass bulb (length 2 cm) containing already powdered Be, the radon was concentrated with the help of liquid air. The Rn-Be-tube (50-500 mCurie) was put into the interior of a cylindrical sample of platinum. Why platinum? Its large excess of neutrons might have been the reason, perhaps together with its ready availability. An extra neutron could possibly trigger β-decay. However, Pt did not show any effect at all. Aluminium – a pill tube? – happened to be tested next. Aluminium had been a hot topic on its own account since the Joliot-Curies had established, a few months earlier, that polonium's α-rays turned it into phosphorus, the new radioactive species emitting positive electrons, those detected by Anderson in cosmic rays. This time Fermi's counter revealed a strong activity, suggestive of the transformation of ${}_{13}Al^{27}$ into ${}_{11}Na^{24}$ under α-emission, followed by β-decay resulting in the stable isotope ${}_{12}Mg^{24}$. His report, initially in Italian, was dated 25 March 1934. All the elements at his disposal were checked in a hurry. Some of the lighter elements were tested in the form of paraffin and water: H, C and O did not give appreciable effects, though.

Fermi's thrilling finds were warmly received by the experimentalists, particularly by the most distinguished among them, Ernest Rutherford, Cambridge. On 10 May 1934 the team reported also on uranium.

When U was separated from its β-active products and subsequently bombarded with neutrons, several reactions showed up, among which a β-decay with a half-time of 13 minutes. Fermi c.s. had the impression that a new species was at issue, an element with atomic number 93: ${}_{92}U^{238} + n^1 \rightarrow {}_{92}U^{239} \rightarrow {}_{93}X^{239} + 1$ e. The new element was provisionally baptized 'ausonium', a possibly implied element number 94 'hesperium', discrete references to Rome and Italy, respectively. The new elements, though, were short-lived: in December 1938 the quartet Hahn, Strassmann, Meitner and Frisch showed that it had been a matter of 'fission'.

Slow neutrons

After the summer holidays, in mid-September 1934, Fermi's team planned to standardize the procedures and establish a semi-quantitative scale of the induced activities, starting with silver. Accidentally, they noticed that when the Ag cylinder was irradiated on a wooden table, the effect was far larger, than on the marble table in the same room. The material of the table, apparently, played a role. Paraffin wax, already investigated before by the Joliot-Curies and Chadwick – and by Fermi himself, as we saw above –, was now used as an analog of wood. October 20, 1934, a Saturday, Fermi, irradiated the silver cylinder through a layer of paraffin, hurried it to a counter and noticed an increase in activity by a factor of about 100. A 'filter' of pure carbon did not have any effect, so it seemed that it was the hydrogens that did the job. Fermi realized that neutrons traveling through paraffin wax regularly hit hydrogen nuclei of about the same mass, inelastic collisions that caused them to slow down. The apparently *fast* neutrons escaping from the source were turned into *slow* ones with, in the end, thermal velocities (2600 m.sec^{-1}); these thermal neutrons were, quite unexpectedly, *more* readily absorbed by silver nuclei. Among the tested metals was also cadmium: it was the exception in that it only absorbed neutrons under γ-emission, but did not feature β-decay.
One of the experiments concerned a plate of rhodium, the most sensitive metal, on top of a paraffin cylinder, just above a Rn-Be-tube (Figure 2). When a hat-like other paraffin cylinder was put over the Rh plate, the latter's activity *increased*. It seemed as if the slow neutrons diffused also into the upper part, were scattered around in the wax and eventually, on escaping, hit the Rh plate also from above. A similar effect was noticed when the Rh was covered with a layer of beryllium, carbon or silicon: these layers behaved like mirrors, causing a back-scattering of neutrons that had passed the Rh plate. Boron did not work. On the other hand, some materials had a *decreasing* effect when brought as a layer inbetween the rhodium plate and the neutron source, particularly yttrium, cadmium and, indeed, the boron that didn't work on top of the rhodium. For Cd, for instance, the half-value thickness of such a layer was 0.014 g.cm^{-2}, corresponding to a nuclear cross-section of 10,000x10^{-24} cm^2. The neutrons were *absorbed,* not scattered, by these materials, so much was sure.



◄ **FIG. 2:** A paraffin wax cylinder P containing a hole for the Rn-Be-source S (kept in a long tube). The materials to be studied were put on top. One of the most active was rhodium; it was used as a detector to distinguish 'scattering' from 'absorption'. Here it carries a glass dish, which was filled *e.g.* with boric acid solutions to study boron's effect.

Already in 1935 Fermi was nominated for the Nobel Prize for Physics. In 1938 a crescendo of proposals finally resulted in his being awarded the prize "for his demonstrations of the existence of new radioactive elements produced by neutron irradiation and for his related discovery of nuclear reactions brought about by slow neutrons". With his wife Laura and their children he left afterwards for Columbia University, New York, for a six months stay which turned into emigration.
If Fermi was generally considered the 'Pope' of physics, his team functioned as a true Curia. It was the time that men like Max Planck and Niels Bohr were among those elected member of Rome's newly founded Pontifical Academy of Sciences. Fermi, then, had no problems in acknowledging, on occasion, his great debt to the curator of Italy's stock of radiumchloride, Giulio Cesare Trabacchi: indeed, what would a Pope do without whom he called his 'Divine Providence' ? ■

Acknowledgment

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About the author

Henk Kubbinga (University of Groningen) is a member of the EPS-History of Physics Group. With some delay his book *The molecularization of the world picture, or the rise of the Universum Arausiacum* has finally appeared in print (Groningen University Press, 2009).

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PHYSICS IN DAILY LIFE:
HEATING PROBLEMS

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It's winter; our house is warm and cozy, but we need fresh air. In an earlier daily-life column (*Fresh air*, EPN 36/2) we noticed that if we instantly refresh our room with cold outside air while keeping the heating off, the temperature will return almost to its original value once thermal equilibrium has been re-established. The reason is that the heat capacity of the air is small compared to that of all the solid-state stuff in our room, certainly if we include part of the walls. In turn, this is because the number density of atoms in solids is roughly 1000 times the density in air at ambient temperature and pressure, while the contribution to the heat capacity of every single atom, whether in a solid, a liquid or a gas, is roughly the same: a few times the Boltzmann constant k.

Incidentally: just how instantaneous must the venting be in order for the argument to be valid? Obviously, the venting time has to be small compared to the thermal relaxation time of the room. But this is not simple to assess. For one thing: temperature equilibration of a room is not a single-relaxation time process, given the wide variety in thermal relaxation times RC of all the objects in the room (R is the thermal resistance and C the heat capacity). The relaxation time of an empty wine glass, for example, may be just half a minute; the value for a full bottle of wine is about three hours, and that for the walls and other large objects may be even longer. In any case, the values are large enough so that 'instantaneously' refreshing the air is easily achieved. Subsequently, convection in combination with the small heat capacity of the air will rapidly raise the air temperature almost to its original level. Old-fashioned as this procedure may be, from an energy-saving perspective it has an advantage over having a continuous draught of cold air through our room, since this would make the temperature gradient near our skin steeper and make us feel cold.

The process of warming up the air in our room offers an interesting physics problem. If we compare the two situations, cold air and warm air in our room, in which of the two cases will the total kinetic energy of the air molecules in our room be largest, if we ignore convection currents? The answer seems obvious: since the mean kinetic energy of a gas molecule is directly proportional to temperature (*viz., 3/2 kT*), the total kinetic energy should go up.

But there is a catch. While the temperature goes up, some of the air will escape, since the atmospheric pressure will not change, being dictated by the outside pressure. And lo and behold: if we may consider air as an ideal gas (which is a very good approximation at ambient conditions) the density is inversely proportional to the temperature at constant pressure. And since the volume of our room remains constant, the number of molecules in it also decreases inversely proportional to the temperature.

So, the answer may be somewhat surprising: if we heat our room, the total kinetic energy of the air in it remains exactly constant. ■

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