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Energy for the future – the nuclear option
50 years of controlled nuclear fusion
40 years of the EPS
Physics in daily life: counting flames
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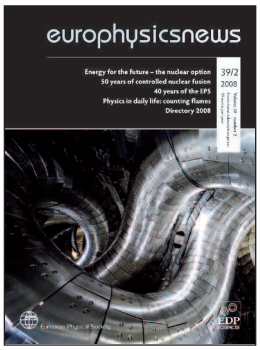

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cover picture: The Large Helical Device is billed as the "largest superconducting stellarator in the world". This Japanese fusion research device consists of intertwined coils of superconducting material, and is designed to contain a 100-million-degree nuclear fusion plasma. The research aims to solve the many engineering challenges that must be overcome in order for fusion reactors to produce more energy than they consume.

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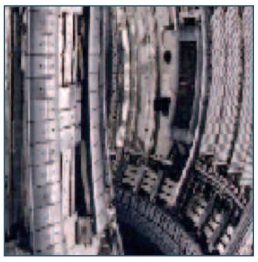
The 40th anniversary of the EPS



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Editor: Claude Sébenne
Email: claude.sebenne@impmc.jussieu.fr

Science Editor: George Morrison
Email: g.c.morrison@bham.ac.uk

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

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

Director of Publication: Jean-Marc Quilbé

EDP Sciences
Managing Director: Jean-Marc Quilbé

Production: Agnès Henri
Email: henri@edpsciences.org

Advertising: Isaline Boulven
Email: boulven@edpsciences.org

Address: EDP Sciences
17 avenue du Hoggar, BP 112, PA de Courtabœuf,
F-91944 Les Ulis Cedex A • France
tel: +33 169 18 75 75 / **fax:** +33 169 28 84 91
web: www.edpsciences.org

EPS Secretariat
address: EPS • 6 rue des Frères Lumière
BP 2136 • F-68060 Mulhouse Cedex • France
tel: +33 389 32 94 40 / **fax:** +33 389 32 94 49
web: www.eps.org

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Friedrich Wagner

ON ENERGY, PRESENTING THE NEW EPS POSITION PAPER

>>> EDITORIAL

In 1938, 60 years ago, Otto Hahn and Fritz Straßmann were searching for elements heavier than uranium. They could show by chemical analysis that the irradiation of uranium with neutrons – the technique selected to produce transuranic elements – surprisingly led to barium, a lighter element. Nuclear fission was detected. Lise Meitner was involved in the early studies and contributed significantly to the analysis and interpretation of the results. Lise Meitner was born in 1878, 130 years ago and died in 1968, in the same year as Otto Hahn, 40 years ago from today.

The magic of the decadal system will doubtless draw this year some public attention to the discovery of nuclear fission and its main actors. It may also stir up the debate on the use of nuclear energy. The EPS has recently published the position paper "Energy for the future – the nuclear option". The EPS provides expert advice and policy statements via position papers - to communicate its views on scientific issues that may have an impact on society. This position paper was written by members of the Nuclear Physics Division of EPS and approved by the Executive Committee. None of the authors has any connection to nuclear industry.

The position paper can be downloaded from the EPS home page (www.eps.org/about-us/position-papers); printed copies are also available; the part summarizing the EPS position appears after the present Editorial. Its format is different to other position papers. It not only states the position but it also gives the reasoning in a scientific/technical part containing also detailed references. This format, which allows the authors to cautiously develop their adjunct arguments, has been selected in a field which usually only accepts yes or no, black or white.

Though the climate challenge is global, the primary problem, the burning of fossil fuels, is a concern treated mostly locally in Europe. Electricity production in some countries is nearly 100% CO_2-free and 100% carbon based in others. In the average, 57 % of Europe's electricity supply releases CO_2. Nevertheless, I am afraid that the burning of oil, gas and specifically coal for electricity production will continue world-wide. It is rather schizophrenic, that on one side large and important panels warn on global temperature rise and its consequences and that international rules of CO_2 reduction should be established whereas on the other side there is a public worry - driven by the rising costs of transportation - whether the peak of known oil reserves has meanwhile been overcome - or not.

The stock market quotation of Petrobras rose by 15% after the discovery of a new oil field close to the Brazilian coast had been announced; Norway and Russia quarrel about the exact course of the continental shelf which would define the share in the exploitation of the gas and oil fields of the Barents- and Kara Sea; Russia throws its hat into the ring (actually its flag onto the ocean floor) for the exploitation of the Artic fuel resources; Canada may become the worlds largest oil producer because its oil-sands become economically attractive at an oil prize of 80$/barrel; the countries abutting the Caspian Sea have agreed on their respective shares in the exploitation of the resources beneath it. This all implies – I cannot interpret it differently – that the fossil resources in stock will be used. To me, CO_2 separation and safe storage is one of the most imminent tasks.

Before 2020, Germany has to replace 40 to 50 GW, Europe about 400 GW and the world about 2000 GW of outdated electricity power stations by new ones. This represents an excellent chance to save CO_2 by replacing those power stations with an efficiency of ~ 38% by modern ones which range from 45 to 55 % efficiency or also by nuclear power. But the last decades have not been properly used to prepare for this critical period of enforced replacement. CCS (carbon-capture and sequestration) technology and licensed storage cavities are not available on the necessary large scales. Also the public has not been prepared for an acceptance of new power stations. Though available energy is the most important commodity for those without natural resources, there is little public tolerance to accepting new power stations. This remarkable situation provoked a comment by President Putin at his last press conference in office: "Germany closes its nuclear power stations and abstains from coal".

The expansion of wind power stations and photovoltaic systems happens with largely different speeds in Europe. Wind energy strongly develops in Germany, Spain and Denmark. The installation of PV systems occurs nearly exclusively in Germany. In 2006, 3.8 GWp have been installed which delivered 0.5% of the consumed electricity. Wind and PV shares of Europe's electricity production are 2.1% and 0.05%, respectively. A long way is still to go and wind and PV electricity do not supersede nuclear and fossil power stations. Both would be fully viable sources in the case that electricity could be stored on a large scale and in a cost-effective manner. This field necessitates much more research than is presently implemented.

Then, there remains nuclear power, fission and - in the longer run - fusion. In some European countries, fission is not allowed by law, in others, it has been decided to terminate nuclear power stations whereas in Finland, France and Rumania new ones are being built and in England, in the Baltic countries and in Slovakia they are considered.

Europe seems intent on proceeding without a common energy policy. The present supply structures are fragmented; the plans for the future are extremely disperse. It will be a long way to come to a joint strategy. The next decade will bring Europe another interesting economic experiment when countries with CO_2-free electricity production compete with those which have to pay for the extra costs of carbon CCS (carbon-capture and sequestration) or CO_2 release into the atmosphere. One has to keep in mind that the availability and use of electric power still correlates positively with the global domestic product, our standard of living. The economics of the energy market might lead to a melt-down of beloved positions. Then, a European energy policy might eventually emerge. Let us hope that it will arrive still on time.

If the most modern technology, specifically safety technology, is employed, the risks of nuclear energy can be assessed and judged. Risks are relative, not absolute. The risks of nuclear energy have to be compared with those of other energy technologies, with those of economic decline due to a lack of affordable energy, of growing import dependence (which ultimately might invite political blackmail), and – above all - with the risks of climate change.

The recent incidents in peripheral systems in Forsmark, Brunsbüttel and Krümmel, although they have never reached any serious accident level, have, however, demonstrated that the necessary care, the proactive safety planning and the regular maintenance and inspection is not necessarily part of the operational culture – let alone the capability properly to respond to a case drawing public attention. There is no doubt also to the "supporters", who publicly argue in favour of nuclear energy, that its future necessitates strict and close surveillance by independent authorities. More than the prestige of a utility or supplier is at stake.

The EPS position paper on nuclear energy comes to the following major recommendations:

- Given the environmental problems our planet is presently facing, the present generation owes it to the future generations not to forgo a technology that has the proven ability to deliver electricity reliably and safely without CO_2 emission. Nuclear power can and should make an important contribution to a portfolio of sources having low CO_2 emissions.
- There is a clear need for education in nuclear science and preservation of nuclear knowledge as well as for long-term research into both nuclear fission and fusion and methods of waste incineration, transmutation and storage.

The last point is of specific concern for a physics society like EPS. The halt of publicly funded research into nuclear energy technology in some countries is an inexcusable mistake. Nations with a long tradition in science and technology have a specific commitment and responsibility to develop every meaningful option for clean energy sources. Nuclear energy has still a tremendous potential for research and development as outlined by the Generation IV goals. Because of the complexity of nuclear energy and because of the safety and proliferation risks, industrialized countries may not leave the development of fission reactors to those alone who badly need more energy. As research takes a long time to come to fruition, the decision today to pull out will be at the

disadvantage of the next generation, for which the options available will have been reduced. But they were not involved in the decision process on termination.

One aspect which has to be addressed is the Chernobyl accident. Can one still recommend nuclear energy in the face of this accident and its casualties? The annex of the position paper quotes the WHO report and gives the then-known death toll within the emergency workers at the scene (liquidators) and the children with thyroid cancer. WHO also considers the expected number of victims who will die prematurely from radiation-induced cancer. The reflection on the deplorable casualties cannot, however, be separated from the reasons which led specifically to this accident and the measures which were taken by the authorities to limit the consequences. It was known that the RBMK reactor type represented a potential risk because of the design error of a positive void coefficient. Despite this flaw, 11 reactors of this type are still in operation – 22 years after the accident - with improved safety however. This fact demonstrates once more how complex and tedious it is to change the energy system; romantic views are out of place in this field.

It should not be forgotten that this reactor exploded in 1986 not out of normal operation but while a dangerous experiment was being carried out. The position paper points to the eminent role the IAEA plays in ensuring control of nuclear power stations and in supporting the operational teams. Modern reactors and future ones cannot be assessed via the technical risks inherent to the RBMK reactor type and the fatal consequences due to spurious action. The risks of nuclear energy have to be assessed along side the risks involved with the allocation of other forms of energy and the environmental consequences of their use. Such an assessment of the various options along with the threat of global warming leads many to finally accept the risks of nuclear energy.

Pope Benedict XVI stated in his Angelus prayer in Castel Gandolfo in July 2007, on the occasion of the 50th anniversary of the IAEA, that the commitment toward a peaceful and safe nuclear technology is more up-to-date than ever. Maybe, he had in mind the First Commandment: "Thou shalt have no other gods before me". This command does not rule out the existence of other gods and it cannot be applied to modern multi-ethnic societies whose peaceful co-existence rests on tolerance. This tolerance may also become a vital element of a European-wide discussion for a jointly carried energy policy. The tenor of the EPS position paper is a step in this direction. ■

Friedrich Wagner,
President of the EPS

ENERGY FOR THE FUTURE
THE NUCLEAR OPTION

>>> EPS POSITION PAPER

The European Physical Society (EPS) is an independent body funded by contributions from national physical societies, other bodies and individual members. It represents over 100,000 physicists and can call on expertise in all areas where physics is involved.

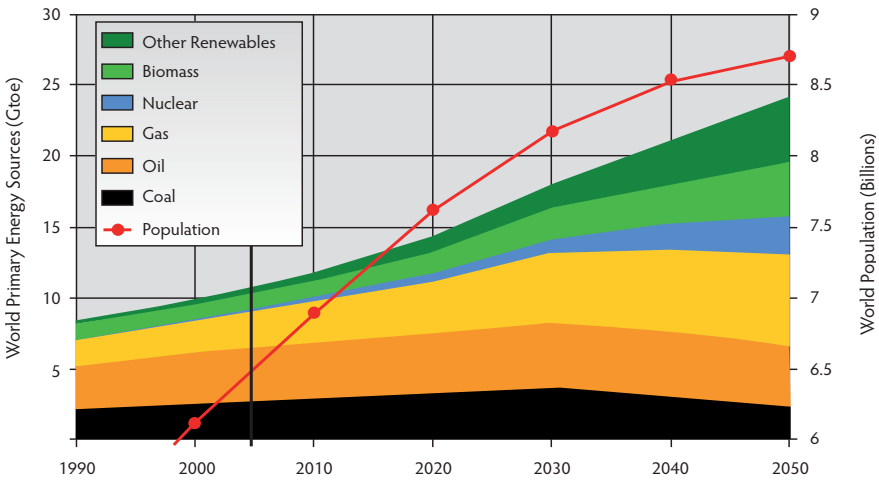
The Position Paper consists of two parts, the EPS position, summarising the recommendations, and a scientific/technical part. The scientific/technical part is essential to the Position Paper as it contains all facts and arguments that form the basis of the EPS position.

The objective of the Position Paper

The use of nuclear power for electricity generation is the subject of worldwide debate: some countries increase its exploitation substantially, others gradually phase it out, still others forbid its use by law. This Position Paper aims at a balanced presentation of the pros and cons of nuclear power and at informing both decision makers and the general public by communicating verifiable facts. It aims to contribute to a democratic debate which acknowledges scientific and technical facts as well as people's proper concerns.

Future energy consumption and generation of electricity

The increase of the world population from 6.5 billion today to an estimated 8.7 billion in 2050 will be accompanied by a 1.7% increase in energy demand per year. No one source will be able to supply the energy needs of future generations. In Europe, about one third of the energy produced comes in the form of electric energy, 31.0% of which is produced by nuclear power plants and 14.7% from renewable energy sources. Although the contribution from renewable energy •••



▲ **Scenario of world primary energy sources for a sustainable future. Note the suppressed zero point of the population scale.**

··· sources has grown significantly since the beginning of the 1990s, the demand for electricity cannot be satisfied realistically without the nuclear contribution.

Need for a CO_2 free energy cycle

The emission of anthropogenic greenhouse gases, among which carbon dioxide is the main contributor, has amplified the natural greenhouse effect and led to global warming. The main contribution stems from burning fossil fuels. A further increase will have decisive effects on life on earth. An energy cycle with the lowest possible CO_2 emission is called for wherever possible to combat climate change. Nuclear power plants produce electricity without CO_2 emission.

Nuclear power generation today

Worldwide, 435 nuclear power plants are in operation and produce 16% of the world's electricity. They deliver a reliable base-load and peak-load of electricity. The Chernobyl accident resulted in extensive discussions of nuclear power plant safety and serious concerns were expressed. European nuclear capacity will probably not expand much in the near future, whereas a significant expansion is foreseen in China, India, Japan, and the Republic of Korea.

Concerns

As any energy source nuclear energy generation is not free of hazards. The safety of nuclear power plants, disposal of waste, possible proliferation and extremists' threats are all matters of serious concern. How far the associated risks can be considered acceptable is a matter of judgement that has to take into account the specific risks of alternative energy sources. This judgement must be made rationally on the basis of technical arguments, scientific findings, open discussion of evidence and in comparison with the hazards of other energy sources.

Nuclear power generation in the future

In response to safety concerns, a new generation of reactors (Generation III) was developed that features advanced safety technology and improved accident prevention with the aim that in the extremely unlikely event of a reactor-core melt down all radioactive material would be retained inside the containment system.

In 2002 an international working group presented concepts for Generation IV reactors, which are inherently safe. They also feature improved economics for electricity generation, leave reduced amounts of nuclear wastes needing disposal and show increased proliferation resistance. Although research is still required, some of these systems are expected to be operational in 2030.

Accelerator Driven Systems (ADS) offer the possibility of the transmutation of plutonium and the minor actinides that pose the main long-term radioactive hazard of today's fission reactors. They also have the potential to contribute substantially to large-scale energy production beyond 2020.

Fusion reactors produce CO_2-free energy by fusing deuterium and tritium. In contrast to fission reactors there is essentially no long-lived radioactive waste. This promising option may be available in the second half of this century.

The EPS position

Given the environmental problems our planet is presently facing, we owe it to ourselves and future generations not to forgo a technology that has the proven ability to deliver electricity reliably and safely without CO_2 emission. Nuclear power can and should make an important contribution to a portfolio of sources having low CO_2 emissions. This will only be possible if public support is obtained through an open democratic debate that respects people's concerns and is informed by verifiable scientific and technical facts.

Since electricity production from nuclear power is opposed in some European countries and research into nuclear fission is supported in only a few, the number of students in this field is declining and the number of knowledgeable people in nuclear science is likewise decreasing. There is a clear need for education in nuclear science and preservation of nuclear knowledge as well as for long-term research into both nuclear fission and fusion and methods of waste incineration, transmutation and storage.

Europe needs to stay abreast of developments in reactor design independently of any decision about their construction in Europe. This is an important subsidiary reason for investment in nuclear reactor RD&D and is essential if Europe is to be able to follow programmes in rapidly developing countries like China and India, that are committed to building nuclear power stations, and to help ensure their safety, for instance, through active participation in the IAEA. ■

The EPS Executive Committee

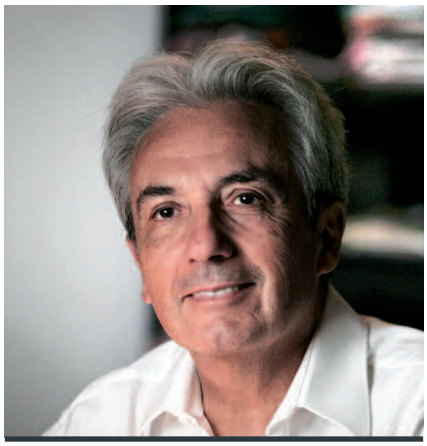
NOTE
The full document can be obtained at the EPS website: www.eps.org/about-us/position-papers

NOBEL PRIZE IN PHYSICS 2007: ALBERT FERT

>>> PRIZE

After a very successful year in terms of prizes, Albert Fert was awarded the 2007 Nobel prize in Physics together with Peter Grünberg for the discovery of Giant Magnetoresistance (GMR). The GMR was reported almost simultaneously in 1988 on Fe/Cr multilayers by Albert Fert (Baibich *et al*, *Phys. Rev. Lett.* **61**, 2412, 1988) and on Fe/Cr/Fe trilayers by Peter Grünberg (Binash *et al*, *Phys. Rev. B* **39**, 4828, 1989). Fert's paper presented both the experimental results and their interpretation on the basis of his previous work on the spin dependent conduction in ferromagnetic materials. As the change of resistance between the parallel and antiparallel magnetic configurations of the Fe/Cr multilayer was as large as 80%, Fert coined the expression "Giant Magnetoresistance" to describe such huge effects. The discovery of the GMR created a considerable stir, first because it immediately turned out that it was opening a new research field in science and technology (called today spintronics), and secondly because the potential of applications became rapidly very clear. In 2003, with 2455 citations (more than 3500 in 2007), Fert's 1988 article was ranked 6 in the "Top Ten" of the most cited Physical Review Letters since the creation of the review in 1953.

GMR and spintronics take their roots in the pioneering work of Albert Fert at the end of the 60's on the influence of the spin on the mobility of electrons in ferromagnetic materials (Fert and Campbell, *Phys. Rev. Lett.* **21**, 1190, 1968; *J. Phys. F* **6**, 849, 1976, for a review). After having experimentally demonstrated that, in a ferromagnetic metal, the electrons of opposite spin directions (spin up and spin down along the magnetization axis) carry different currents (as originally suggested by Sir Neville Mott), Fert worked out the well known "two current model" of the electrical conduction in ferromagnetic metals. He also showed that very large spin asymmetries of the conduction can be obtained by doping the ferromagnetic metal with impurities selected to scatter very differently the spin up and spin down electrons (iron or cobalt impurities in nickel, for example, scatter the spin down electrons 20 times more strongly than the spin up electrons). Moreover, some experiments of Fert on ternary alloys were already introducing the idea that he will exploit later to produce the GMR effects. He showed that the resistivity of a ternary alloy, for example $N_{1-x}(A_{x-y},B_y)$, is strongly enhanced if the scattering by the impurities A and B have inverse spin asymmetries. Replacing the impurities A and B by magnetic layers A and B, one equally expects a large enhancement of the resistivity when their magnetizations are in opposite directions, which is the basic concept of the GMR. However, this concept can work only if the thickness of the layers is in the nanometer range. The fabrication of metallic multilayers with thicknesses in this range became technologically possible in the mid-80's.



▲ Portrait of Albert Fert by Bruno Fert (in visu)

The discovery of GMR triggered immediately an extensive research attracting researchers worldwide in the new field of spintronics. Albert Fert has always been at the forefront of the field and made with his group and collaborators outstanding contributions to a number of emerging directions in spintronics. Together with Levy and Zhang, Fert worked out the first quantum mechanical theory of the GMR in 1990 (*Phys. Rev. Lett.* **65**, 1643, 1990). Initially studied in the CIP configuration (Current In the Plane), experiments soon followed exploring the Current Perpendicular to the Plane (CPP) geometry. CPP-GMR is not only interesting for applications but also because it has revealed spin accumulations effects, which were analyzed in a seminal paper (T. Valet and A. Fert, *Phys. Rev. B* **48**, 7099, 1993). These effects still play a major role in the most recent developments of spintronics such as spintronics with semiconductors (A. Fert *et al*, I*EEE Transactions on Electron Devices*, **54**(5), 921, 2007), or molecular spintronics (L. Hueso *et al.*, *Nature* **445**, 410, 2007). He reported a very high magnetoresistance (1800% at low temperature) in magnetic tunnel junctions (MTJ) based on the magnetic oxide $La_{2/3}Sr_{1/3}MnO_3$ (*Appl. Phys. Lett.* **82**, 233, 2003) and demonstrated the active role of the electronic properties of the tunnel barrier in MTJ (Science 286, 507, 1999). He was also the first in collaboration with a Spanish group to report on a significant magnetoresistance in MgO-based MTJ (*Appl. Phys. Lett.* **79**, 1655, 2001), which are now developed worldwide. Last but not least, he contributed significantly to the study of the spin transfer phenomenon. Originally predicted by John Slonczewski from IBM, a group in Cornell in 2000 and the group of Fert in 2001 (Grollier *et al.*, *Appl. Phys. Lett.* **78**, 3663, 2001) were the first to observe the reversal of a magnetization by spin transfer-induced precessions. These results triggered an intense activity of research and, today, the precessional magnetic switching by spin transfer torque is mastered in several types of magnetic devices, metallic multilayers, spin valves or tunnel junctions.

To conclude, one should recall that Albert Fert conducted his research in close collaboration with the company Thomson-CSF (now Thales) since 1986. It started from an informal collaboration between his group at the Laboratoire de Physique des Solides d'Orsay and the Physics group at Central Research Laboratory of Thomson-CSF headed by Alain Friederich. Both then co-founded in 1995 the "Unité Mixte de Physique CNRS/Thales" laboratory associated to Université Paris-Sud, needless to say a successful example of collaboration between academy and industry.

On behalf of his group and close collaborators, I would like to congratulate Albert Fert for the award of the Nobel Prize and thank him warmly for his scientific guidance over the past twenty years. •••

••• Emeritus Professor of Université Paris-Sud since October 2006, Albert was happy to have plenty of time for research. The Nobel Prize has slightly changed his plans… After this very busy year, we know that he is more than impatient to find the time to sit down and contribute to the future of spintronics. ■

Frédéric Petroff,
CNRS senior scientist and
Deputy-director of Unité Mixte de
Physique CNRS/Thales, Orsay, France

NOBEL IN PHYSICS 2007: PETER GRÜNBERG

>>> PRIZE

The German Nobel laureate in Physics 2007, Peter Grünberg, is a lucid example of a physicist dedicated to basic research who at one point has a sensitive nose for a potential application of his findings and suddenly finds himself amid an overwhelming technological development. When his groundbreaking paper was initially rejected he then first submitted a patent even before his French colleague, Albert Fert, and his group had submitted the results of their independent discovery. The submitted patent covered a "Magnetic field sensor with ferromagnetic, thin layer" for reading magnetically stored data. Nine years later the first product, the read head of hard disk drives, was put on the market, unfortunately not by a European company. This revolutionary discovery at the advent of the emerging field of spinelectronics is another memorable lesson to be learned for research management. It underscores once more the priceless value of curiosity driven basic research. The persistently demanded accelerated transfer of knowledge from basic research to the market occurred in this case silently, without big strategic planning. In this context, the pioneering work of Stuart Parkin at the IBM Almaden Research Centre on spin-engineered magnetic multilayers, mediating between basic research and commercialization of novel magnetic sensor and memory concepts, should also be mentioned.

The initial step toward the extraordinary discovery on Peter Grünberg's part goes back to the finding in 1986 of an antiparallel orientation of the magnetizations of two iron layers separated by a chromium spacer layer. As probing technique Peter Grünberg used inelastic Brillouin light scattering (BLS) employing a high-contrast tandem Fabry-Pérot interferometer. With this rather specialized method he solely was able to determine the sign of the interlayer exchange coupling constant, oscillating between positive and negative values for parallel and antiparallel orientations of the ferromagnetic layers, respectively. By means of the BLS technique Peter Grünberg had already set a highlight in 1977 by observing bulk and surface spin waves in the magnetic semiconductor EuO. In the following years he had studied numerically and experimentally the spin wave spectra of dipolar or exchange coupled ferromagnetic layers, providing a base for his later discovery.

▲ Peter Grünberg © Forschungszentrum Jülich

It is characteristic of Peter Grünberg to follow certain trains of thoughts with persistency, independent of side-tracking hot topics attracting temporarily much attention. To some extent this approach has a certain similarity to that of Albert Fert whose discovery is rooted to spin dependent transport dating back to the late 60s. Both scientists are indulging their passion for basic research. Peter Grünberg, in particular, has developed a certain descriptive imagination of how the phenomena might come about and usually likes to explain them in rather simple terms. It is unforgettable for attendees of several international conferences on magnetism in the 80s how Peter Grünberg demonstrated experimentally live on stage the anisotropy of magnetic and exchange coupled layers. He used samples floating on top of water, which were exposed to opposite poles of two permanent magnets under different directions outside the vessel. This mission proved to be very impressive and successful. Last summer, for instance, he gave another example of his visions about giant magnetoresistance (GMR) at a small internal workshop of his institute, where he elaborated on several remaining fundamental questions he would like to get solved. This persistent drive goes with Peter Grünberg for decades as the author of this article could experience during longstanding cooperation with him. These are dating back to the late 70s, when both were part of the collaboration on light scattering in magnetic thin films between the Max-Planck-Institute for Solid State Research in Stuttgart and the Research Centre in Jülich, where Peter Grünberg had settled. In the years from 1983 through 1997 this cooperation was continued in the framework of the Collaborative Research Centre "SFB 125" and "SFB 341" between the University of Köln, the Research Centre Jülich and the RWTH Aachen University, where the author is located. The success of this Collaborative Research Centre was also owed in part to the efforts of the late Prof. Werner Zinn, director at the Institute of Solid State Research of the Research Centre Jülich. Under his guidance and with his favourable support Peter Grünberg had started his outstanding career in Jülich.

In spite of all his extraordinary achievements, Peter Grünberg has preserved his very modest nature as well as amiable and cordial personality, which many friends and scientists have enjoyed and esteemed very highly over all these years. ■

Gernot Güntherodt,
Professor of Experimental Solid
State Physics, RWTH Aachen University,
52056 Aachen, Germany

40 YEARS OF THE EPS:

VIEWS FROM PRESIDENTS ZICHICHI AND FRIEDEL

During this year celebrating the 40th anniversary of the EPS, Europhysics News publish a sequence on this event in each issue. In the first one, EPN 39/1, the article of H. Kubbinga recalled the early years of the EPS. For the next issues, contributions have been asked from several former Presidents of the EPS and will be published, possibly in the order of presidencies, together with some testimonies from other former EPS actors. In the present 39/2 issue we have the great pleasure to publish the reflections of former Presidents A. Zichichi (1978-80, Italy) and J. Friedel (1982-84, France)

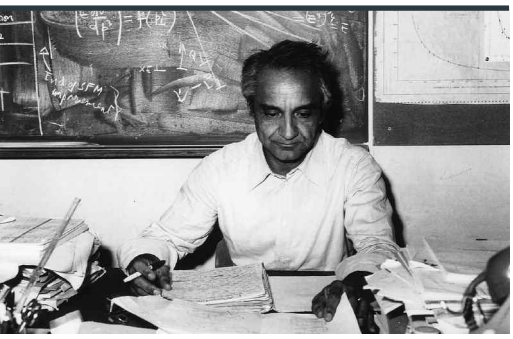
The EPS during two difficult years (1978–1980)

Antonino Zichichi (Italy)
EPS President (1978-1980), and the EPS youngest founding member (1968)

During my period of presidency, there are a few points of the EPS activities which are worth remembering.

The first one is the implementation of actions in order to soften the very difficult conditions of Eastern physicists, dictated by the existence of the iron curtain. EPS succeeded in creating, for the first time, a "spirit" of reciprocal confidence between the East and the West. For the first time, research physicists were allowed to spend some time in Western universities and research centres. This was the result of our visits in Moscow, Bucharest (Romania), East Berlin, Novosibirsk (Siberia) and Budapest (Hungary).

▼ **Pr. Antonino Zichichi**



The 1979 EPS Conference in Geneva was the best proof that the exchange programme for scientific activities was effectively improving the situation. Let us not forget that it was ten more years to go before the fall of the Berlin Wall.

The second point is the establishment of the International Seminars on the "European Great Projects". This initiative covered four fields: (1) Sub-nuclear Physics; (2) Nuclear Fusion; (3) Astrophysics and (4) Synchrotron Radiation. For the first time, all these activities were brought together and, on March 1979 in Rome, the European Great Projects were presented and discussed jointly, thanks to EPS.

It is probably of interest to recall my opening remarks at this conference:

"The future of physics research, up to the year 2000, will clearly be based on the scientific choices we are making now. Compared with the recent past we have therefore two basic points to consider. When I started my research activity in the fifties a few physicists could do an experiment in a year or so. The average number of people and the time needed to accomplish research work have both drastically increased since then. And this is not all. As mentioned above, we are reaching the state where our decisions severely affect future generations of physicists. For example, a student, now in high school, will be a physicist with the right age to work with one of the facilities to be built in the four fields. He will be working in collaboration with many other people. Yet the source of new ideas will always be a single person."

"The European Physical Society, whose members are physicists working in all fields of physics, and living all over Europe – from North to South, from East to West – was given the task of establishing a suitable forum where an important part of the future of physics could be presented and discussed by the European community of physicists. The members responded with enthusiasm to the EPS proposal: 250 of them, actively engaged in these important areas of research, came to Rome to attend the EPS International Seminar, whose proceedings are the content of the present volume".

"It was the first time that EPS members, working in different branches of physics, had the opportunity to meet and discuss large future projects. The interest in this new EPS Seminar was such – and this we could only find out after the Seminar was over – that the forecast for the future appears promising."

"Let us hope that an EPS forum can be established where the status of all European Great Projects can be reviewed and discussed regularly."

In the picture below there is a view of the Aula Magna "Pietro da Cortona" of the famous Palazzo Barberini in Rome where the EPS conference was held.

▲ **The Aula Magna "Pietro da Cortona" of Palazzo Barberini.**

▼ **President A. Zichichi and EPS Executive Committee members meet with H.H. John Paul II during the March 1979 Conference in Rome**

The third point is the meeting of the EPS Executive Council with H.H. John Paul II, in the Vatican. This is the meeting where the Pope gave the speech celebrating Galileo Galilei as the father of modern Science, thus opening the doors of the Catholic Church to Science.

This played an invaluable role in eradicating the danger of a Nuclear Holocaust, and in confronting, through factual

projects, the danger of an Environmental Holocaust in the undeclared war between the planet's North (the rich) and South ••• ••• (the poor). The scientific community could never have hoped to obtain such an outstanding support for the implementation of this extremely difficult task.

It is the EPS who had the cultural courage to establish a close link with the Pope who, for the first time in the history of modern culture, has distinguished Science from Technology with his famous statement: "Man could perish from the effects of technology that he himself develops, not from the truth that he discovers by means of scientific research". This statement is forged in iron and displayed at the Ettore Majorana Foundation and Centre for Scientific Culture in Erice, a Centre with has kept, during many decades, a close collaboration with EPS.

During the meeting the EPS Council expressed its gratitude to John Paul II who, with his strong cultural support, allowed EPS to be at the centre of the public opinion, worldwide, and gave it the opportunity to implement its task of enhancing physics research in all fields of frontier Science. ■

The EPS as I knew it

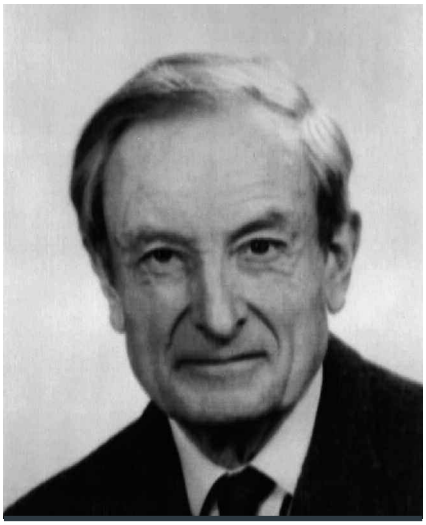
Jacques Friedel (France)
President of the EPS, 1982-1984

When envisaged at a meeting in Rome in the late 60's, the European Physical Society looked like a dream, between the remembrance of a Europe of passport-free travel before the First World War and the post-war increasingly rigid separation between East and West. This dream, the high-energy physicists were the first to have a taste of, by the creation of CERN, which united their efforts in the West and quickly developed working contacts with the East. Fermi's heritage pushed the Italians to take an active part in this enterprise; and their new summer schools of physics, in Varenna and Trieste, to be followed by Erice, led them to the idea that CERN should be the nucleus of a European Physical Society extending over the whole of Europe and replacing the National Societies in their role of stimulating both research and teaching. This wonderful dream tried to forget about the existence and possible usefulness of National Societies and the then very different aspects of research in various European countries, notably in its organization in East and West. Many discussions had to take place before EPS was launched at CERN in 1968, on a compromise between a Society of Individual Members and a Society of National Physical Societies. Representatives of both kinds of members were, from the start, elected into the General Assembly; the meetings and a small secretariat were housed in Geneva Battelle Institute; and a complex but realistic compromise on dues and membership to the Assembly, obtained by the clear-sightedness and tenacity of people such as Francis Netter, brought life to the Society.

I did not take part in the preliminaries, but was sent as a delegate of the French Physical Society to one of the first meetings of the **General Assembly**, chaired by the Director of CERN, my old friend Bernard Grégory. The Society had to be organized; and we created specialized divisions, notably, with my help, a large Condensed Matter Division, including solids and liquids but also "soft matter", already dear to Pierre-Gilles de Gennes, such as polymers and liquid crystals.

Being then engaged in renovating our "Journal de Physique", I was quickly included in a **Publication Committee,** created to implement an ambitious OCDE plan to build a European Physics Journal out of existing ones from Italy, England and the Netherlands. This did not please the Germans or the French and left the Eastern Countries indifferent. The final and much more modest decision was a mere labelling by EPS of a number of national physical journals. Later efforts to regroup some of them occurred after my presidency, under the impulsion of people like Philippe Nozières and Denis Jérome. My last publication meeting occurred in an overexcited Prague, just after the "spring revolution", when the people loudly protested in all cafés in town against the recent arrival of Russian tanks and the death of Jan Pallach.

My next role in EPS was in the **Executive Committee**, with repeated meetings at EPS's secretariat in Petit-Lancy,



▲ Pr. Jacques Friedel

which I found congenial and stimulating under the Rudberg's genial presidency. It was a good opportunity to learn and judge the underlying strengths and tensions in the Society, these last being more between the smaller and larger countries than between scientific domains or between East and West. The Committee normally proposed new Presidents, and I am rather proud of having successfully proposed H. Casimir, who turned out to be one of our scientifically stimulating stars as well as a famous physicist in industry. H. Casimir reported to me later on the low esteem into which his old master Pauli was placing such activities in industry. But his knowledge and judgements in recent developments of physics were deep and varied; and as a member of an active group of European industrialists interested in research (EIRMA), he was the first to push EPS in that direction. During a General Assembly in Bucharest, he also did not hesitate to tell President Ceausescu to his face, at a large dinner, that his obstruction to free exchanges of scientists with the West was both shameful and counterproductive.

When elected to the **Presidency of EPS** (1982), I found the Society in financial difficulties, owing to the reluctance of Eastern countries and members to pay increasing dues for an expanded secretariat aptly ruled by G. Thomas. My predecessor had accepted the shift of the secretariat to cheaper Budapest. While agreeing to part of this move, in a country which was then trying to open itself to the West, I did not like to loose the insurance of stability of

the Swiss franc as well as the stimulating proximity of CERN and of many other scientific and industrial research activities; indeed I said that I would be equally against a move to France for the same reasons. The Assembly followed me because there was a financial alternative: working within our connections from Ecole Polytechnique, Albert Messiah, an EPS individual member, and myself had started enlisting the support for EPS of most large French industrial firms, in exchange for a membership that opened to them new European connections. I was convinced that similar successes could be obtained in other countries if we developed a real and visible interest for applications, both in our Divisions and in a yearly general meeting on Applied Physics as well as in more specialised discussions. Indeed I held in Bucharest a general meeting on energy, which, after the oil crisis, gave to many European physicists a taste for solar energy. This was also a rare occasion to meet a number of celebrated Russian physicists, including old Kapitza, who did not leave their country easily. Perhaps the renewed feeling of an energy crisis will stimulate again European industry to renew interest in long term research and EPS to take part in that move. But I should say that already at the end of my presidency, I could not prevent the secession of the opticians who, under André Maréchal's leadership, created a European union of their own! If specialised activities on teaching were a constant preoccupation, my efforts to create a Division of Biophysics were probably premature and failed. Also our efforts to create summer schools for countries of the south of Europe with help of UNESCO and the equivalent of Gordon Conferences as Europhysics meetings were, in the long run, superseded by more local efforts. Despite a secession of the liquid section, the Condensed Matter Division has flourished, including after my presidency a meeting in Pisa with a night long free-for-all discussion of Müller's recent results on cuprate superconductors! During my presidency, I was able to convince Martin Peter to ask for the help of EPS to distribute a yearly prize created by Hewlett-Packard. Under Casimir's chairmanship, I took part in the two first juries, which would make this prize one of the paths to the Nobel.

Having been involved in the development of synchrotron radiation in Orsay, I was interested in the possible extension as a larger European source. I organized a large EPS meeting in Copenhagen to present and discuss all the large experimental set ups in physics then planned or in construction in Europe. The synchrotron radiation source was presented for the first time in some details; and, after more studies by the European Science Foundation and inter-governmental agreements, it found its way to Grenoble as ESRF. Of the many other schemes, I especially remember a supercomputer just acquired by the British Meteorology Agency, planned to predict local weather more accurately in space and time. Owing to the turbulent nature of climate, this effort would, shortly after, be switched to more general studies of the hothouse effect. The potential interest of the Copenhagen meeting did not escape the Americans, and my friend David Lazarus tried, too late, to have the American Physical Society included. But these contacts led to agreements on common memberships of the two Societies. Despite my efforts, similar agreements failed with the Japanese Physical Society, despite my good contacts with a Society, which had celebrated its centenary in 1977, as the British and the French ones had done two years before.

For a new President of the East, I wished to recommend a Russian physicist and more especially Youri Sharvine, a low temperature experimentalist of Nobel potentialities whom I knew from a stay in Orsay and his activity in the EPS. I thought it would be a show of strength of our Society to choose a representative of the largest and most scientifically active country of Eastern Europe, but with a minimal representation and financial contribution to EPS. These delegates, all from the Russian Academy of Sciences, and especially Sharvine, were keen to develop the purely scientific contacts, which they found in EPS. Ursu, the flashier President of the Rumanian Physical Society, organiser of the recent Bucharest meeting, was preferred. The whole picture has changed: Sharvine is now dead and most of his solid state colleagues that we used to receive in Paris are now dispersed through the world. But I believe that the problem remains. ■

Conference announcements

An EPS/SFP Conference

The Conference on "Energy: A challenge for 21st century physics" will be held in Les Houches, France, 2-6 June 2008.

>>> **Website:** www.sfpnet.fr

>>> **E-mails:** J.L. Bobin, bobin@ccr.jussieu.fr or Thomas Hamacher, tih@ipp.mpg.de

X-08

The "21st International Conference on X-Ray and inner shell process" will be held in Paris, France, 22-27 June 2008. It covers a large field: astrophysics, atomic or nuclear physics, plasma or solid state physics, biophysics or chemical physics…

>>> **Website:** http://x08.spectro.jussieu.fr/

EPAC'08

The 11th European Particle Accelerator Conference will be held in Genoa, Italy, 23-27 June 2008. This is the last of the series. It will be replaced by an annual IPAC series (International Particle Accelerator Conferences) rotating every three years from Asia (2010: Kyoto, Japan) to Europe (2011: Valencia, Spain) then America (2012: New-Orleans, USA).

>>> **Website:** www.epac08.org

DIAMOND 2008

The International Conference "Diamond 2008" will be held in Sitges, Spain, 7-11 September 2008. It will review the latest scientific and technological aspects of vapour growth diamond, natural and synthetic diamond, and related materials such as carbon nanotubes, diamond-like carbon and wide gap nitrides particularly cubic boron nitride.

>>> **Website:** www.diamond-conference.elsevier.com

EL 2008

The "14th International Workshop on Inorganic and Organic Electroluminescence" and the "2008 International Conference on the Science and Technology of Emissive Displays and Lighting" will be held from 9 to 12 September 2008 in the Grand Hotel Duca D'Este, 00011 Bagni di Tivoli, Rome, Italy

>>> **Website:** www.EL2008.it

>>> **E-mail:** EL2008@frascati.enea.it

FIRST STEP TO NOBEL PRIZE IN PHYSICS

In the past, several articles were published in Europhysics News on the International Young Physicists Tournament (*EPN* **37/1**) and the International Physics Olympiads (*EPN* **38/1**, **/2** and **/5**). The above title is the name of another international physics competition for secondary school students. It has evolved on the basis of a similar competition held in Poland [1], has been held annually since the 1992/93 academic year and has attracted over 2000 participants. The initiative for both, the Polish and the First Step competition came from the late Dr Waldemar Gorzkowski, who was running it by his inspiring enthusiasm until last year, as he did over decades with the International Physics Olympiads. Since its beginning the First Step has been supported in an essential way by the Institute of Physics of the Polish Academy of Sciences.

The competition is open to anyone younger than 20 years on 31 March of the current year who is not already a student of a university or higher education college. Each participant has to present a paper prepared individually, written in English and dealing with any theme related to physics. The paper must have a research character and therefore the emphasis is on its originality, correctness and sound argumentation, verifiable by experiment or calculation. In short it should satisfy criteria, which are normally required by peer review international publications. The papers are refereed by an international panel. The authors of the best papers are awarded by an invitation to spend one month doing research in the Physics Institute of Polish Academy and their papers are published in the annual proceedings of the competition. Other participants who do not belong to the above group but distinguish themselves from the remaining competitors, receive an honourable mention in one of the following categories: research paper, contributions, and instruments. Other details about the competition can be found at its homepage www.ifpan.edu.pl/firststep.

In the first 14 years of the competition [2], there were 1956 participants coming from 76 countries. The largest cohorts came from India (264), Turkey (235), Iran (144) and Ukraine (131). From 30 European countries of which 21 are members of the European Union, there were 291 participants with the largest numbers from Romania (73) and Poland (57). For all these years there have been only 11 papers submitted by students coming from Austria, Belgium, Estonia, Finland, Germany, Portugal, Spain and Sweden taken together. The highest rates of distinguished papers were by students from Serbia and Montenegro (10 awards and 12 honourable mentions among 27 submitted papers), Czech Republic (2+14 of 19), USA (13+26 of 56) and Singapore (6+14 of 29).

For example, in the 2005/06 competition, the 4 distinguished papers were the following [2]:

1. Z. Aminnayeri (Tehran, Iran): Analysis of movement of ink in water – an experimental study;
2. S.A. Hadzhieva (Sofia, Bulgaria): Mechanics of super-bouncing;
3. A.P. Kamantsev (Chelyabinsk, Russia): Measuring the temperature dependence of the air thermal conductivity under constant pressure;
4. Y. Zheng (Singapore): Study of extra-solar planet formation by observing eclipsing binaries.

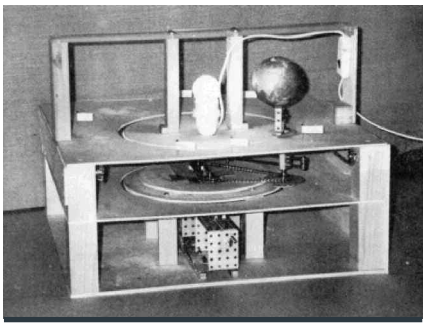
The aim of this and other competitions is to attract talented youngsters toward sciences. European structures aiming at a continuous prominent role in the future must show their concern by recognizing the work of the organizers of such competitions and providing the necessary support. ■

Viktor Urumov,
Saints Cyril and Methodius University, Skopje, Macedonia

References

[1] International Physics Competitions, Ed. W. Gorzkowski, Institut Fyziki PAN, Warszawa (1999).

[2] First Step to Nobel Prize in Physics, Proceedings of the Fourteenth International Competition in Research Projects in Physics for High School Students (2005/06), Eds. W. Gorzkowski, P. Janiszewski, W. Dobrowolski and J. Mostowski, Institut Fyziki PAN, Warszawa (2007).



▲ **A model built by M. Müller, Gymnasium in Münchenstein, Switzerland, to demonstrate Earth motion around the Sun, taking into account characteristic subtleties of the motion. (First Step Award in 1993/94, *Acta Physica Polonica A* 88, Suppl. S-49 (1995).)**

Call for candidates

Dear Members of the Nuclear Physics Division,

The Board of the EPS NPD is organising elections to replace outgoing members. Two vacancies are announced herewith. Nominations should be made on the attached form and, together with a short CV (1 A4 page) and a statement of acceptance from the candidate, should be sent either by email to **d.lee@eps.org**, or by regular mail to:
EPS, Nuclear Physics Division Board Candidate BP 2136, F-68060 Mulhouse Cedex (France)
Deadline for receipt of nominations: 31 May 2008. Self-nomination is not possible.
The members of the Board of the Nuclear Physics Division are expected to attend Board meetings, which take place twice a year. Among the activities of the Nuclear Physics Division are: the organisation of the EPS Conference on Nuclear Physics, awarding two prestigious prizes, the Lise Meitner Prize and the IBA Prize in Applied Nuclear Science, providing input to the EPS on issues related to nuclear physics and relations to other European and international bodies interested in nuclear physics and policy.
For further information go to **http://ific.uv.es/epsnpb/**

ABOUT "REVISITING FARM HALL" >>> LETTER

I am replying to the article *Revisiting Farm Hall*, A. LUCAS, *EPN* **38/4** p.25 (2007)

I have a rather different opinion on the main subject of the article, namely the responsibilities of German nuclear scientists in the atomic effort in WWII, the content of the Farm Hall transcripts, and in particular the rôle of Werner Heisenberg (WH).

My main point is that from the evidence presented in the article (which is accurate) the conclusions of the author do not follow at all. A careful reading reflects mainly the aim of the author to inculpate the Germans scientists in that they were really after the bomb, but that partly by mistakes and partly because the military authorities did not ever become seriously committed to making the bomb, they never produced it, indeed were far from production.

The possibility of an atomic bomb was fairly clear at least to six countries (UK, USA, France, Russia, Japan and Germany) after the discovery of nuclear fission (Dec., 1938), with the attendant emission of neutrons giving rise to the possibility of a chain reaction. Both US and German scientists advised their authorities of this possibility around early 1939. To confound these statements [*e.g.* Geiger and Bothe are supposed to have said "(the bomb) must be done at once"; or "if there is a … chance, it must be done" (Dec., 1939)] with an organized effort to make the explosive is far from the reality. The article unfortunately abounds in such unjustified extrapolations, as any alert reader will notice [1].

Explorations of the new energy source started in Germany certainly before the Allies, from end-Sept., 1939. The nuclear reactor was extensively considered in order to produce the chain reaction. Around 1940/41 the Germans decided against U-235 separation (too difficult) and for using heavy water as the moderator; *not* a complete mistake: after the war, such reactors were built; a German chemist misunderstood the necessary graphite purification (with a suspicion of intentionality), and the Germans disposed of the powerful Norwegian facility for heavy water.

Two crucial events took place in 1942 (glossed over in the article). First, in March WH convinced Speer, the minister for armament, that the bomb was beyond German capabilities at that time of the war (the army had failed in front of Moscow, Dec., 41). Secondly, in June the same year, WH made an order-of-magnitude correct guess of the critical mass (a few kilos, " Ein Ananas"). In my paper [2] I have written why I think WH gave a wrong answer in Farm Hall when asked. Most of the opponents of WH cite this "mistake", but at least Lucas also quotes the (contrary) error in the estimate of Peierls, namely a too optimistic value. As Lucas said, the Germans concentrated on the Peenemünde weapons (V-1 and V-2), and left aside an all-out effort on the bomb, neither was such an effort being recommended by WH. He only wanted a reactor to work.

I take literally J. Berstein´s phrase quoted by Lucas: "The German scientists behaved morally in an immoral regime, while the Allied counterparts did just the opposite". In fact, the Allied programme went full-steam ahead in early 1943, when it was overwhelmingly clear to them that the Germans were not producing the bomb. But remember, they started the programme through fear of the Germans; they accelerated the program (Oppenheimer dixit) after the VE day; they dropped the second (plutonium) bomb when Japan was, through Switzerland and Russia, trying to seek conditions for surrender. So, who were the bad guys?

One point I disagree with Lucas is in his recommending J. Bernstein´s version of the Farm Hall. He (JB) is also very unfair in relating the visit of WH to Poland in Dec. 1943 (see Ref. 8 in [2]), and he, together with Goudsmit, are the originators of the legend on the evil of the Germans and the bomb. The opinion of Todorov [3], von Meyenn [4], and •••

••• Rechenberg [5] is that the legend was concocted to distract public opinion on the culpability of the Allies (not only Nagasaki; the needless and indescriminate bombing of Dresden was also a crime). Of course, there is also another "legend" leaning to the other side, propagated by R. Jungk in '*Brighter Than a Thousand Suns*', but it is already discredited.

Lucas also cites the Bohr-WH conversation in Copenhaguen in 1941; contrary to his presentation, the letters from the former to WH, made public recently, do not incriminate WH much, as the reader can see for himself; the play by M. Frayn (British) is also fair (and accurate, if somewhat speculative) with regard to WH. Again, I suggest that the reader considers these documents by him/her self (but please read the *official* C. Frank report on Farm Hall, *not* Bernstein's!). Incidentally, the claim by Lucas that the Germans openly felt superior scientists to the Allies is wholly unsupported by factual evidence.

A nice point was cleared up by Hans Bethe (Lucas is curiously silent here), namely the mistake of Bohr in confusing WH's design of a reactor with that of a bomb (cf. [6]. There are also a couple of facts overlooked by Lucas, e.g. the important role of Houtermans [H] in the German acceptance of the plutonium approach; the transmission by H of information to the US through emigrating Jews (cf. [2]). And Lucas is being somewhat unreasonable in incriminating the German Farm Hall prisoners by their wanting to return to Germany; at least in England they were well fed! History is told by the winners, and Belgium undoubtedly suffered a lot under the German occupation.

As a final point, the author insists too much on the "*Lesart*", the apparent concoction of the Germans in Farm Hall, after hearing of the nuclear bombing of Japan in August, 1945. Certainly von Weizsäcker "sweetens" the facts a little, but the FH Transcripts put the finger on the truth, and neither WH nor O. Hahn (not to speak of von Laue) did totally "accept" the Lesart version. ■

Luis J. Boya,
Univ. of Zaragoza, Spain • luisjo@unizar.es

References

[1] *Am. J. Phys* **73**(9), 2005: Resource Letter MP-1, *The Manhattan Project*. All important books & articles are qoted there.

[2] Luis J. Boya, "Heisenberg y el Proyecto Atómico Alemán", *Revista Iberoamericana de Física* **3**(1), 2007, p. 78

[3] Ivan Todorov, *Werner Heisenberg*, arXiv/physics 0503235 (Todorov is a well-known theoretician from Bulgaria)

[4] Karl von Meyenn, "Heisenberg, los Nazis y la bomba alemana", *Revista de Libros* (Madrid). Nov-2002. (A very good historian).

[5] Helmut Rechenberg. Private communications, München (2004 and 2006): See also his *History of Quantum Theory*, Vol. VI, p. 1013; with Jadish Mehra.

[6] Hans Bethe, *Physics ToDay*, Jul-2000

AMAND A. LUCAS RESPONDS ››› LETTER

Prof. Boya accuses me of many sins. I will address the main accusation only which is that my aim was to "*inculpate*" the German scientists for "*being after the bomb*" by "*extrapolating*" from what they declared at Farm Hall.

The Farm Hall Transcripts (FHT) by themselves make it emphatically clear that the German nuclear scientists intended to work on all applications of nuclear fission including the military. In mid-1939 under orders from the Army Weapons Bureau, they gathered in Berlin and collectively committed themselves to building a bomb. They went home and started preparation work to that end. Throughout the war several of them repeatedly tried to interest top Nazi authorities in the promises offered by nuclear explosives. These are facts, not "*extrapolations*". That uranium enrichment was hard and that the plutonium route turned out to be long and treacherous, plus a multitude of other adverse circumstances, may have prevented them from succeeding. But the fact remains that they were willing to build an atomic bomb for Hitler. And more than one of them had the decency to deny that their failure to do so stemmed from a collective, deliberate decision to refrain from ever trying, as von Weizsäcker would have liked the world to believe by promulgating the Lesart.

The statement by Prof. Boya that "*Heisenberg only wanted a reactor to work*" is highly tendentious because it propagates the message of the attenuated version of the Lesart. Namely that the Germans avoided working on a bomb to concentrate only on a peaceful nuclear reactor. Heisenberg did know perfectly well, as the FHT show explicitly, that there is a great difference between a slow-neutron reactor and a fast-neutron atomic bomb. But in February and June 1942, he expounded that difference and explained to top Nazi officials and Wehrmacht generals that the slow-neutron reactor on which he was working would breed plutonium for a fast-neutron bomb. No amount of arguing is ever going to dismiss that as mere "*extrapolations*" on my part. All scientists know for a fact that there is no such thing as a peaceful nuclear reactor. The German scientists were perfectly aware of that fact as early as 1940. As long as they did not stop working on the reactor, they did not stop working on the bomb project, even if the bomb wasn't for the immediate future. The only way to make nuclear reactors peaceful is by signing an international political agreement not to extract plutonium for military purpose out of used reactor fuel. Needless to say, proposing any such agreement in time of war is "*talking moonshine*".

Let me repeat what I tried to express in my paper. The German nuclear scientists could have justified their work by claiming, as Heisenberg did after the war, that they wanted to deter the Allies from

attacking the Reich with nuclear weapons. The Allied scientists had the same legitimisation for their own work. The main difference, and what a difference, is that the former worked with no sense of urgency and knowingly for a gangster government, while the latter worked feverishly against the ominous menace of a thousand years of Herrenvolk tyranny. However brutal this fact may be, it is not even what underlies the "*legend on the evil of the Germans and the bomb*", a "*legend*" which Prof. Boya accuses Goudsmit and Bernstein of creating. The true outrage is the Lesart, clearly and repeatedly stated in the FHT for all to read. After Hiroshima, the leading German scientists felt it necessary to cover their nuclear activities with a virtuous cloak. It is this moral message presented and propagated as the historical truth which constitutes the real legend at the source of the post war dispute on the responsibility of the German nuclear scientists.

When Prof. Boya raises the question "*who were the bad guys?*", the implied answer is that the Allied scientists were the bad guys while the Germans were the good guys. Notice that his judgement coïncides exactly with von Weizsäcker's strong version of the Lesart, namely that the good Germans developed a "*peaceful uranium engine*" while the bad Allies produced "*that ghastly weapon of war*". Let's keep in mind however that the good guys von Weizsäcker and Heisenberg did not find nuclear explosives so ghastly when they briefed in person characters such as von Ribbentrop and Himmler about the great promises of uranium and plutonium.

Prof. Boya is right in urging the reader to go directly to the FHT which indeed speak for themselves. He also recommends Bethe's paper in Physics Today (July 2000) about which he states that I remained "*curiously silent*". Bethe's assessment of what Heisenberg knew or knew not is of course highly interesting. But in turn Prof. Boya remains curiously silent about an equally interesting article by David Cassidy which the reader will have no trouble finding since the two articles are next to each other in the same issue of Physics Today. Among other things, Bethe and Cassidy discuss what was the purpose of Heisenberg's cultural propaganda visit to Bohr in Copenhagen in September 1941 and what was said during the conversations. Their speculations, along with those of Frayn in his play, used to be fascinating. But they have suddenly lost nearly all interest with the publication in 2002 of Bohr's unsent letters to Heisenberg in which the actual content of the conversations is revealed. These letters, drafted around 1960, put an end, once and for all, to all speculations about the Copenhagen encounter. The gist of their content had already been largely reported much earlier by Aage Bohr who obviously must have known what took place between his parents and Heisenberg in the family home and at Bohr's Institute. Aage Bohr's opinion may have been suspected by some as biased, but after 2002 there cannot remain any trace of doubt that he was speaking the truth. For historical reliability the letters are on a par with the FHT. Like the FHT, their most valuable import is to shed a blinding light on the true mindset of the German scientists with respect to nuclear weapons well into the war. For the convenience of the reader, I will quote here (with permission from the Niels Bohr Archive; see www.nba.nbi.dk/release.html) from the first and the last drafts.

From Document 1: "*...Personally, I remember every word of our conversations, which took place on a background of extreme sorrow and tension for us here in Denmark. In particular, it made a strong impression both on Margrethe and me, and on everyone at the Institute that the two of you spoke to, that you and Weizsäcker expressed your definite conviction that Germany would win and that it was therefore quite foolish for us to maintain the hope of a different outcome of the war and to be reticent as regards all German offers of cooperation. I also remember quite clearly our conversation in my room at the Institute, where in vague terms you spoke in a manner that could only give me the firm impression that, under your leadership, everything was being done in Germany to develop atomic weapons and that you said that there was no need to talk about details since you were completely familiar with them and had spent the past two years working more or less exclusively on such preparations. I listened to this without speaking since [a] great matter for mankind was at issue in which, despite our personal friendship, we had to be regarded as representatives of two sides engaged in mortal combat…*"

From Document 11: "*…However, what I am thinking of in particular is the conversation we had in my office at the Institute, during which, because of the subject you raised, I carefully fixed in my mind every word that was uttered. It had to make a very strong impression on me that at the very outset you stated that you felt certain that the war, if it lasted sufficiently long, would be decided with atomic weapons.…*

…You added, when I perhaps looked doubtful, that I had to understand that in recent years you had occupied yourself almost exclusively with this question and did not doubt that it could be done. It is therefore quite incomprehensible to me that you should think that you hinted to me that the German physicists would do all they could to prevent such an application of atomic science. During the conversation, which was only very brief, I was naturally very cautious but nevertheless thought a lot about its content, and my alarm was not lessened by hearing from the others at the Institute that Weizsäcker had stated how fortunate it would be for the position of science in Germany after the victory that you could help so significantly towards this end…", beautiful and poignant prose, where one recognizes Bohr's characteristic nuance of thought and circumspection of writing. It is hard to see how Prof. Boya could have read these words with an open mind and still state that "*they do not incriminate Werner Heisenberg much*".

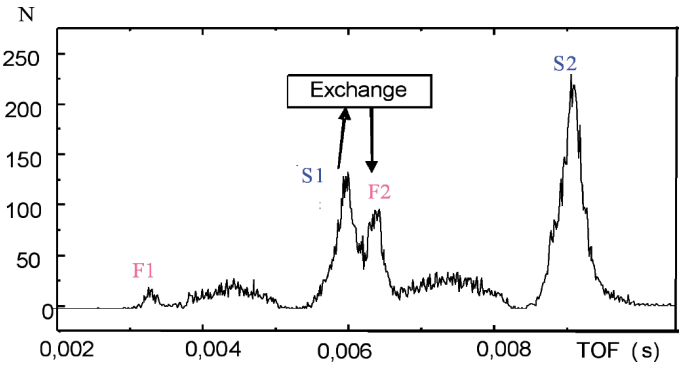
Prof. Boya points out that there is generally no such thing as one single historical truth about war events. Only biased accounts by "victors", he suggests, or by losers or victims, he should have added. Except that in the present case, there are the FHT, which, as I insist in my paper, are documents approaching absolute historical truth as close as it can ever be. The same holds true for the Bohr letters that Prof. Boya dismisses because they contradict so terribly Heisenberg's self-exonerating version of what he said in Copenhagen. ■

Armand A. Lucas

HIGHLIGHTS FROM EUROPEAN JOURNALS

When atoms of two merging beams exchange their internal energies

The internal-state exchange between ground-state and metastable argon atoms, $Ar + Ar^*(^3P_2) \rightarrow Ar^*(^3P_2) + Ar$, is an energetically resonant process resulting from the symmetry of the Ar^*_2 molecule. It has been shown recently that, at low collision energy (a few meV up to a few tens of meV), this exchange is a key process in the production of metastable atom beams of a high brightness and large coherence width. Indeed an almost perfect exchange of velocities between the two partners confers to metastable atoms the very narrow velocity distribution of ground-state atoms in a nozzle beam. Such metastable atom beams are readily useable in a variety of applications in coherent atom optics, such as atom diffraction and interferometry, surface probing at a nanoscale and nano-lithography.



◀ Slow atoms from a first pulse (S1) are overtaken by fast atoms from a second pulse (F2). The exchange process reduces S1 (compared to S2), enhancing F2 (compared to F1).

To our knowledge, measurements of exchange cross section at low collision energy were still lacking. The use of two pulsed merging beams, one of "fast" ground-state atoms (velocity v_f = 560 ms^{-1}), one of slowed down metastable atoms (velocity v_s ranging from 275 ms^{-1} down to 50 ms^{-1}) has allowed us to explore, by time-of-flight (TOF) analysis (figure), collision energies ranging from 8 meV up to 27 meV. Here Ar* atoms are slowed down using a Zeeman slower. These atoms are naturally spin-polarized in state M = +2, which greatly simplifies the theoretical treatment of the collision. ■

J. Grucker, **J. Baudon**, **F. Perales**, **G. Dutier**, **G. Vassilev**, **V. Bocvarski** and **M. Ducloy**, "Study of low-energy resonant metastability exchange in argon by a pulsed merging beam technique", *J. Phys. B: At. Mol. Opt. Phys.* **41**, 021001 (2008)

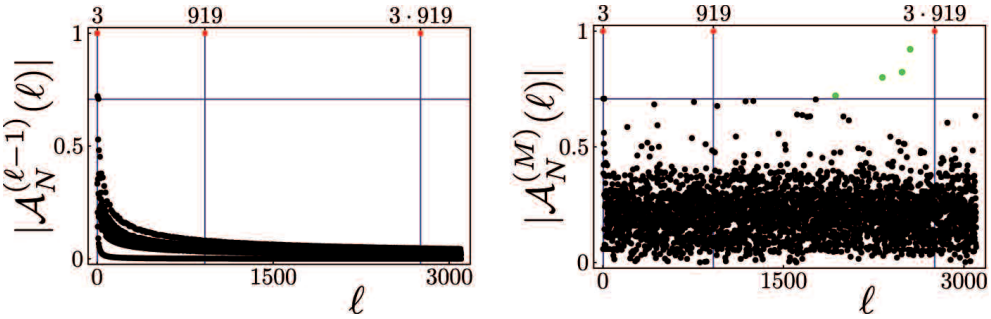
Factorization of numbers with Gauss sums

Factorization of large numbers plays an important role in daily life. Indeed, the security of data transfer protocols in the internet relies on the fact that it is a hard task to reveal the prime factors p and q of a number N whereas the inverse task, the multiplication of p and q, poses no problem. The pair of multiplication and factorization form a so-called trapdoor function since the required computational resources are very different. However, when the eavesdropper owns a quantum computer, he can apply Shor's algorithm, where the required resources grow only polynominally with the number of digits of N.

Recently an alternative route towards factorization solely relying on interference and capitalizing on the periodicity properties of Gauss sums has been proposed and verified by two NMR-experiments and experiments based on cold atoms or short laser pulses. The method relies on the fact that only for a factor the signal, i.e. the absolute value of the Gauss sum, is unity as shown in the Fig. Unfortunately, for every integer N there exist non-factors, the so called ghost factors, where the signal reaches a value close to unity. In order to distinguish such ghost factors from real factors in experiments one needs to amplify this difference.

The present paper shows, that a proper choice of the truncation parameter M of the Gauss sum suppresses the ghost factors below a threshold value and derives the scaling law $M \sim N^{1/4}$. The analysis can be extended to more general exponential sums, where the phase is not necessarily quadratic. ■

M. Stefanak, **W. Merkel**, **W. P. Schleich**, **D. Haase** and **H. Maier**, "Factorization with Gauss sums: scaling properties of ghost factors", *New J. Phys.* **9**, 370 (2007)

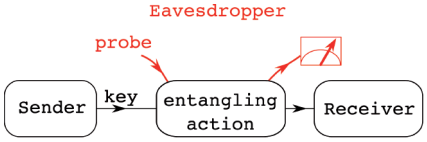


◀ Factorization of N = 9 624 687 = 3 x 919 x 3491 with the help of a complete (left) and a truncated (right) Gauss sum. The green dots are the ghost factors. Here M is 16.

Quantum cryptography is not hacked (yet).

Quantum cryptography or, more properly, quantum key distribution (QKD) is a discipline investigating techniques to grow, out of a pre-shared key, a larger key between two remote parties linked by a quantum and a classical communication channel. The generated key can then be used in various classical cryptographic tasks. The security of QKD protocols stems from the fact that quantum mechanics implies observable communication disturbance by eavesdropping activities. A complete QKD protocol then uses known classical procedures for processing the exchanged key in order to guarantee a shared secret despite eavesdropping attempts.

Conditions for QKD security have been extensively studied for a variety of eavesdropping strategies, or attacks, on different QKD protocols. The rapid evolution of theoretical studies, however, led to diverging understanding of even some fundamental principles. As already very general models of eavesdropping activity are being tackled, some misconceptions are still being published for the simplest type of attacks, the so-called individual attacks.



In particular, misleading claims [*Nature* 447, 372 (2007)] have been advanced following the demonstration of an attack [*Phys. Rev. A* 75, 042327 (2007)], in which the eavesdropper entangles a probe to each exchanged quantum system for later measurement.

With a careful analysis of each procedure required in a complete QKD exchange and how it affects the eavesdropper's potential information gain, the article shows that not only is the standard QKD protocol (BB84) secure against this attack, as expected, but also against the strongest individual attack, which is explicitly described.

Having clarified why the implementation of the claimed "optimal" attack is in no contradiction with established security analysis, the authors conclude that to think that "quantum cryptography is not yet hacked". ■

I.M. Herbauts, **S. Bettelli**, **H. Hübel** and M. **Peev**, : "On the optimality of individual entangling-probe attacks against BB84 quantum key distribution", *Eur. Phys. J. D* **46**, 395 (2008)

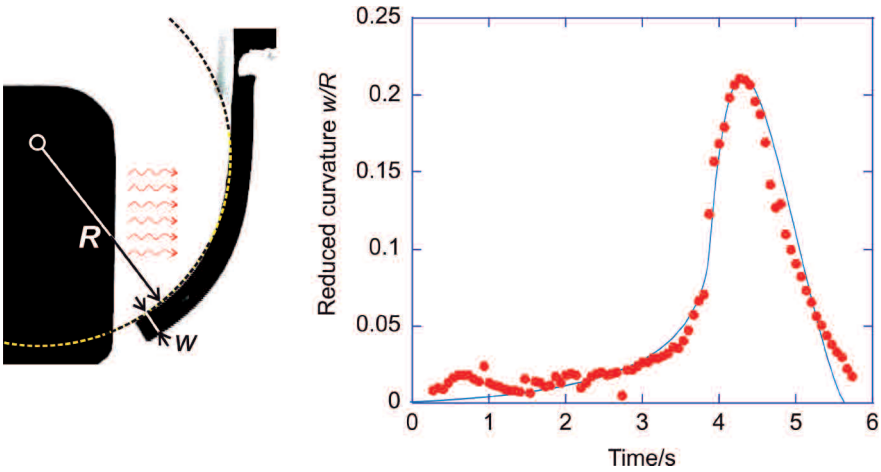
Thermal diffusion and bending kinetics in nematic elastomer cantilever

To make an artificial muscle, we need a soft material that contracts in response to changes in its surroundings. Liquid crystal elastomers (LCE) are very special types of rubber, which combine the long range orientational order of liquid crystals and the polymer elasticity of the weakly crosslinked network to give a range of actuation properties. We have calculated the way a cantilever of this kind of material would bend if heated from one side; this is the kind of response that might be useful for applications in microfluidic valves and pumps, as well as other structures which can respond to their environment.

LCE are particularly attractive as actuators because of their reversible shape change. In simple terms, a uniaxially aligned monodomain nematic LCE contracts when heated and extends back when cooled, in principle, over an infinite number of cycles [Gelling *et al. J. Chem. Phys.*, **88**, 4008 (1988); Kaufhold *et al. Macromol. Chem.*, **192**, 2555 (1991); Tajbakhsh *et al.*, *Euro. Phys. J. E*, **6**, 181 (2001)].

To get a bending motion in a LCE cantilever, we applied a temperature gradient to generate inhomogeneous strain distribution. We modelled the dynamics of a cantilever, which is radiatively heated from one side. The cycle of induced curvature agrees with our experimental data from a range of samples and materials. ■

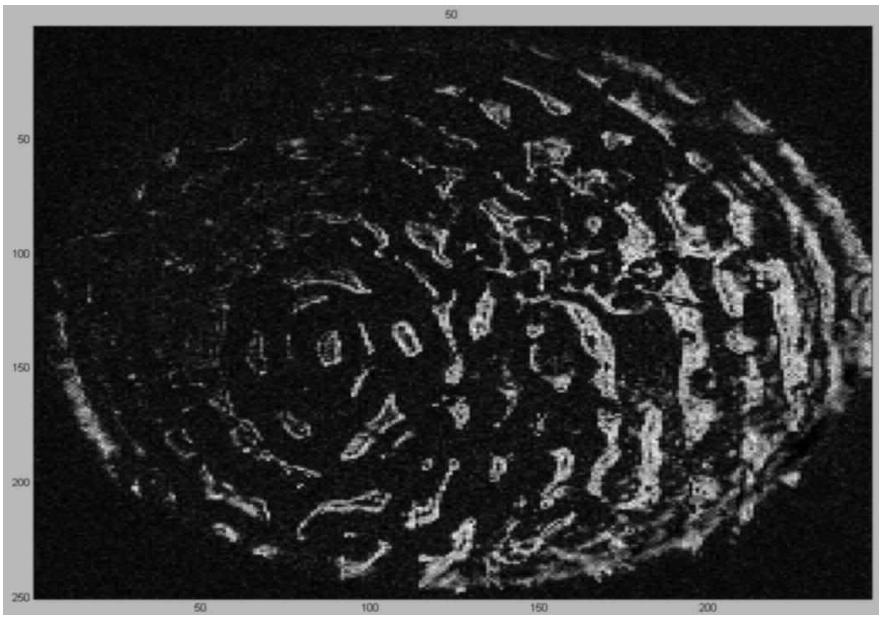
K.K. Hon, **D. Corbett** and **E.M. Terentjev**, 'Thermal diffusion and bending kinetics in nematic elastomer cantilever', *Euro. Phys. J. E*, **25**, 83 (2008).



◄ **Left: The scheme of bending experiment, with the radiative source inducing the curvature 1/R in the cantilever of width w suspended at the top. Right: Experimental reduced curvature w/R vs. time after the start of heating. The solid line is the fit by theoretical equations.**

Topography and tomography of latent fingerprints

Optical coherence tomography (OCT) is a non-invasive, cross-sectional, three-dimensional imaging modality that is based upon the principle of low coherence interferometry. Broadly, OCT has been classified into two categories: time-domain OCT (TD-OCT) and Fourier-domain OCT (FD-OCT). TD-OCT performs two scans: depth-scan also called A-scan and lateral scan called B-scan. In FD-OCT, mechanical scan of TD-OCT is replaced either by a spectrograph, called spectral domain OCT or by a frequency tuned swept-source system, called SS-OCT. So far OCT has been applied for biomedical imaging and diagnosis, characterization of polymer microstructures, paper, paint industry, multi-layered storage media and art conservation studies. We have demonstrated the application of SS-OCT in Forensic Science, *i.e.*, the detection of latent finger prints. A full-field swept-source OCT was developed using a super-luminescent diode and an acousto-optic tunable filter as frequency tuning device and nearly common path interferometer. By means of using amplitude and phase map of the interference fringe signal, simultaneous topography and tomography of latent fingerprints was reconstructed. Low coherence interferometry, selective filtering and hence better resolution are the main advantages of the proposed system over conventional fingerprint detection techniques. The present technique is non-invasive in nature and does not require any physical or chemical processing. ■



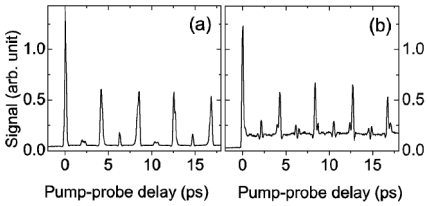
◀ **Reconstructed fingerprint using SS-OCT.**

S.K. Dubey, **D.S. Mehta**, **A. Anand** and **C. Shakher**, "Simultaneous topography and tomography of latent fingerprints using full-field swept-source optical coherence tomography", *J. Opt. A: Pure Appl. Opt.* **10**, 015307 (2008)

Field-free molecular alignment for measuring ionization probability

We investigate an all optical method for determining the probability of molecular ionization induced by femtosecond laser pulses. The approach exploits *post-pulse* molecular alignment appearing when non-spherical molecules interact with intense non-resonant and short laser pulses. Under these conditions, transients of molecular alignment take place periodically under *field-free* conditions. The technique is based on cross defocusing of a probe pulse yielding a signal sensitive to molecular alignment and ionization. A pump pulse is focused in a molecular sample, inducing post-pulse alignment. The degree of alignment is linear with the pump intensity and follows the beam profile. Since the refractive index depends on the magnitude of molecular alignment, the spatial distribution of aligned molecules induces a refractive index gradient which can be seen as a "molecular lens". A time-delayed probe pulse propagating through this lens undergoes a modification of its divergence, and the degree of post-pulse alignment can be evaluated by detecting the probe size variation in the far field region as a function of the pump-probe delay. If ionization occurs during the interaction with the pump pulse, the induced plasma generates an additional refractive index gradient. Analysis of the total cross-defocusing signal provides a quantitative measurement of the ionization probability calibrated with molecular alignment. The experimental set-up is simple and does not require precise calibration of the overall detection efficiency encountered with ion mass spectroscopy. Measurement of the ionization probability of N_2 and ionization ratios N_2^+/Ar^+ and O_2^+/Xe^+ show good agreement with values reported in the literature. Improvement of the accuracy for the low intensities using crossed polarized pump and probe pulses is also shown. ■

V. Loriot, **E. Hertz**, **B. Lavorel**, and **O. Faucher**, "Field-free molecular alignment for measuring ionization probability", *J. Phys. B: At. Mol. Opt. Phys.*, **41**, 015604 (2008)



▲ **Cross-defocusing signal measured for a peak intensity (a) 27 TW/cm^2 (inducing low ionization probability : $P_{ion}<10^{-6}$) and (b) 60 TW/cm^2 ($P_{ion}>10^{-4}$). Ionization significantly modifies the baseline and shape of the pump-probe cross-defocusing signal.**

Antihydrogen production at reduced magnetic field

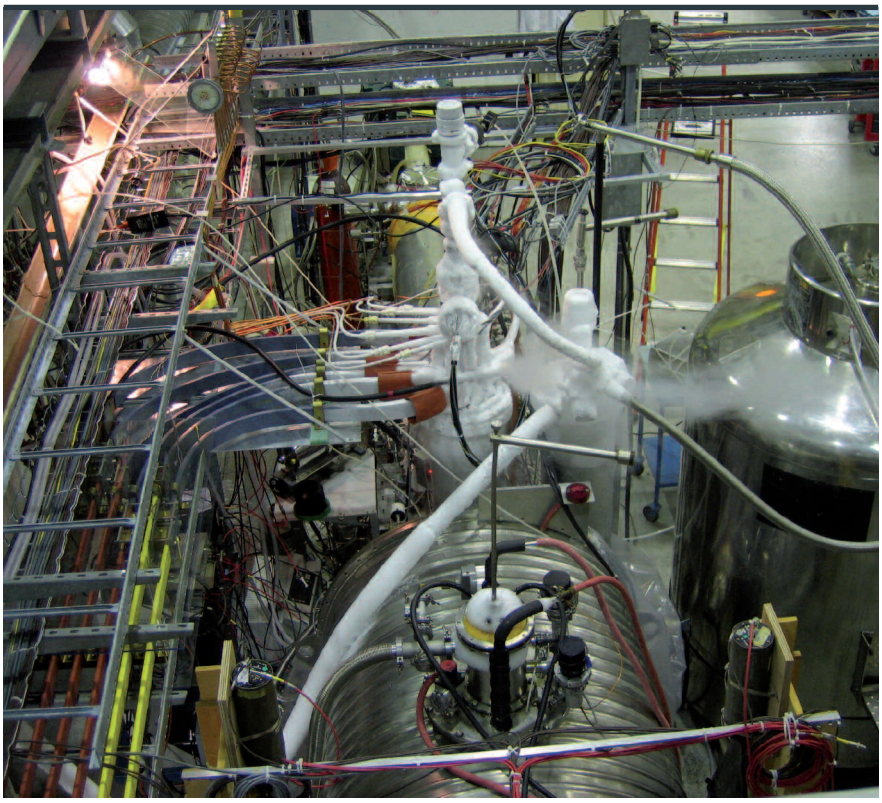
The future of antihydrogen research depends critically on the ability to trap antihydrogen atoms. Antihydrogen produced thus far is not confined, so anti-atoms are free to annihilate on the matter of the experimental apparatus. The ALPHA experiment combines an antihydrogen producing apparatus with a trap for neutral anti-atoms. The antihydrogen is produced by mixing charged antiparticles - antiprotons and positrons - in Penning traps surrounded by superconducting magnet coils that produce a minimum-B configuration around the production volume.

Antihydrogen produced with a kinetic energy smaller than the trapping potential will be confined. The real challenge lies in the fact that the neutral anti-atom trap is not very deep, even though the trap employs the best superconducting technology available. The trap depth for antihydrogen in the ground state is about 0.7 Kelvin per Tesla of magnetic field change. The key point is that the solenoid field in the Penning trap defines the "bottom" of the neutral anti-atom trap. Since the maximum field in the trap is limited by the critical field in the superconductor, it is desirable to make the solenoid field in the Penning trap as small as possible. The ATHENA collaboration, which produced the first antihydrogen from merged plasmas in 2002, employed a solenoid field of 3 T. Antihydrogen production rates of up to several hundred Hz were observed in this field. The rival ATRAP collaboration used a 5 T field. The concern with going to smaller solenoid fields was that the antihydrogen production rate would be greatly reduced - or even completely suppressed.

The ALPHA collaboration put this fear to rest in this article by demonstrating that significant amounts of antihydrogen can be produced in a 1 T field. This is a very encouraging development along the road to antihydrogen trapping. ■

G.B. Andresen and **33 co-authors**, « Production of antihydrogen at reduced magnetic field for anti-atom trapping », *J. Phys. B: At. Mol. Opt. Phys.* **41**, 011001 (2008)

▼ **The ALPHA device during operation at CERN.**



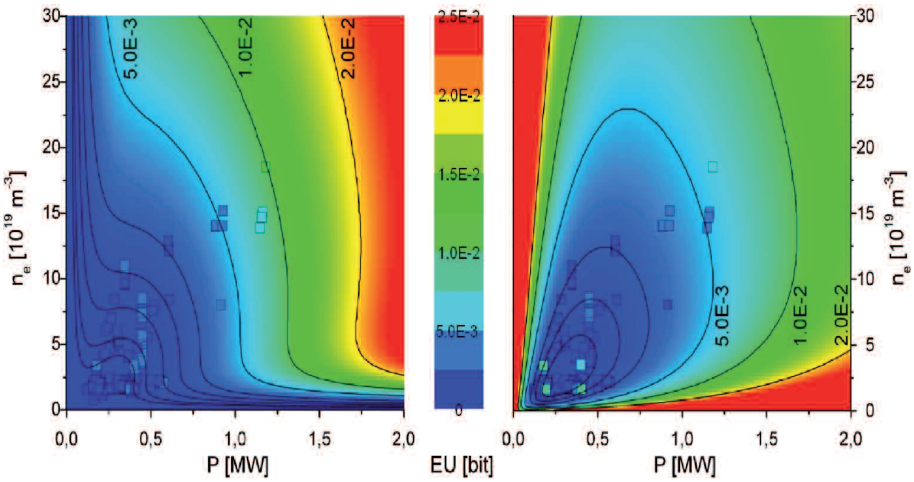
Acceleration by an electromagnetic field of nuclear beta decay

A small but statistically significant increase in the decay rate of Cs-137 has been found in consequence of exposure to intense, low-frequency, plane-wave fields. The result is important both for fundamental physics as well as for potential application to the radiation waste problem. The process depends upon the fact that the beta particle (an electron) emitted in the nuclear decay exists in a radiation-filled environment. With sufficient field intensity, this changes the properties of an electron from a spin-1/2 particle to one that is a superposition of many angular momentum states. This alters the quantum selection rules so that the normally "forbidden" beta decay of Cs-137 can occur more quickly. Caesium 137 has a half-life of about 30 years (it would be about one day were the decay "allowed"), which makes it an important component of high-level waste from nuclear fission. The effect takes advantage of the fact that it is possible to achieve intensity-induced relativistic conditions for the electron if the field frequency is sufficiently low. The process is relativistic since it requires that the interaction energy of the electron with the field must be of the order of mc^2. Because of the extreme mismatch between the wavelength of the radiation and the size of the nucleus, it is important that the nuclear process occur in an isolated "separate universe" where an electron can exist only as the field-dressed particle that provides new angular-momentum pathways for the acceleration of forbidden beta decay. This separate universe was provided in the experiments by using a coaxial configuration on a cw basis. The combination of low frequency and cw operation would provide a low-cost means of waste disposal if the decay rate can be made sufficiently high in future work. ■

H.R. Reiss, "Observation of the acceleration by an electromagnetic field of nuclear beta decay", *EPL*, **81**, 42001 (2008)

The planning of complex measurements

Bayesian theory allows making educated choices for the control variables in complex measurements. As an example we consider the measurement of energy confinement in toroidal magnetic fusion devices. For particular settings of the experiment W7AS the plasma energy content W depends only on the heating power P and the electron density n. The left panel of the figure shows a 2-D plot of the expected information gain on energy confinement from a new measurement in units of bits together with the already available data. The message of this figure is that previously uncovered areas in the (P,n) plain are highly structured and not at all equivalent. The choice of new operating variables can therefore be optimised. In the left panel of the figure the uncertainties of W and the components of (P,n) have been carefully estimated and accounted for in the analysis. Common practise in fusion research is to slight the uncertainties of W and (P,n) altogether, implying constant relative uncertainty of W and exactly known (P,n). Results of the analysis under these conditions are shown in the right panel of the figure. The difference between the two figures is striking and the two ways of analysis suggest entirely different choices of control variables. Of course the assumption of exactly known (P,n) and constant relative uncertainty of W is absurd. The message from the comparison of the two panels is therefore that uncertainties do matter in data analysis and experimental design and should be given considerably more attention than is currently common practise. ■



◀ **The information gain from a future experiment on W=f(P,n) is shown for the cases that uncertainties in W,P, and n have been properly accounted for (left panel) or entirely neglected (right panel).**

R. Preuss, **H. Dreier**, **A. Dinklage** and **V. Dose**, 'Data adaptive control parameter estimation for scaling laws for magnetic fusion devices', *EPL*, **81**, 55001 (2008)

Editor's note: the "Highlights" are 2 years old

The Highlight section of Europhysics News was effectively started in the March-April 2006 issue, EPN 37/2. It followed a call addressed in late 2005 to the Editors-in-chief of a set of Physics Journals, which had to fulfil simple conditions:

- to be under the scientific control of European learned Societies or equivalent European non-profit organizations,
- to have a well established international level in the physical sciences.

Reinforcing the EPS policy on publications, the idea was to advertise the effectiveness of these European Journals in the publication of papers of the highest quality, at the same level as the papers published for example in the APS or AIP journals. It was hoped that potential authors, particularly European ones, would favourably consider the possibility of switching their submission of manuscripts from overseas journals to European ones. We don't know if this hope has transformed into some reality – refined statistical studies would be needed – but we know that the Highlight section is very lively and respects strictly its initial conditions. For this, we are happy to express our gratitude to the Editors-in-chief, who have understood the purpose of our highlights and dutifully provide the necessary material.

It seems that the EPN readers also appreciate the section. Some of them even proposed to collaborate by providing some highlights of their own. This was of course unacceptable considering the spirit of the section, since it would involve either an article from a Journal outside our list, which is excluded, or an article from a Journal on the list, but which would be in conflict with the recommendations of the Editors.

After two years, we have reached a moment when your advice is needed. The number of Highlights is statistically increasing and twice recently a figure of 10 has been reached, taking up 5 EPN pages. It would be unreasonable to ask for significantly shorter contributions: the present length format is a lower limit if the highlight is to remain somewhat understandable. If you favour it, a small increase in number could still be acceptable with the maximum fixed at 12 highlights/issue (6 EPN pages in a total of 30 "active" ones, that is 20%). In any case, we would not put into place an impractical refereeing system to discriminate between the proposals of the Editors. We would simply ask each Editor who has sent more than one Highlight for a given issue to indicate the order of priority so that we know those which can be delayed.

Your Editor views the Highlight section as a significant portion of EPN that is given over to pure and current Physics and is ready to let it occupy the space of one long feature article. He will be happy to receive your opinion on the matter. **Claude.Sebenne@impmc.jussieu.fr**.

50 YEARS OF CONTROLLED NUCLEAR FUSION IN THE EUROPEAN UNION

DOI 10.1051/epn:20082006

Paul Vandenplas [1] and **Gerd H. Wolf** [2]
[1] Laboratory of Plasma Physics, Euratom Association, Royal Military School, Brussels and University of Mons • Belgium
[2] Research Center Jülich FZJ, Euratom Association and Heinrich-Heine-Universität Düsseldorf • Germany

Rather soon after nuclear fission was discovered in 1938 – when its peaceful application as a terrestrial energy resource became recognized – a world-wide dynamic development was set in motion after World War II for its exploitation, with the result that the principal objectives of fission technology were achieved astoundingly quickly. A characteristic feature of this process was the first Conference on the Peaceful Uses of Atomic Energy held in Geneva in 1955, where information on such fission technology became declassified and was exchanged on a world-wide scale. Another feature of this development, in 1957, was the foundation of the International Atomic Energy Agency IAEA with their headquarters in Vienna, which from its very beginning also became a strong supporter of fusion R&D.

Stimulated by these early successes and their spirit of optimism, first concepts for the peaceful use of fusion energy likewise emerged well over fifty years ago, though also classified in their early stages (but fully declassified in 1957 when it became clear that they had no military implications). While at that time some countries already had fusion weapons technology (the hydrogen bomb), the move towards the peaceful use of fusion energy with their huge fuel resources and promising features appeared very attractive and challenging, though extremely difficult and protracted.

Two statements from that period make this particularly clear and typify the tension recognized early on between high expectations and the most intractable physical and technical difficulties. The first is from H. J. Bhabha in his opening speech to the first Conference on the Peaceful Uses of Atomic Energy held in Geneva in 1955: *"I venture to predict that a method will be found for liberating fusion energy in a controlled manner within the next two decades."* Conversely, in the first general article on the fusion issue published 1956 by a scientist from the USA[1], R.F. Post wrote: *"However, the technical problems to be solved seem great indeed. When made aware of these, some physicists would not hesitate to pronounce the problem impossible of solution".*

Despite the latter statement, but well aware of it, a world-wide R&D campaign was initiated with the aim of exploring and developing possible concepts which eventually might lead to a machine (reactor) delivering useful energy from controlled fusion processes. Results from these early years of fusion R&D were reported, among others, at the second Conference on the Peaceful Uses of Atomic Energy held in Geneva in 1958.

In retrospect it is surprising – and this has to be acknowledged – that the basics of those concepts, which nowadays are considered to be the most successful and promising, had already been published at that time, albeit of course without all the plasma physics knowledge, techniques and insights needed for test and proper scale demonstration.

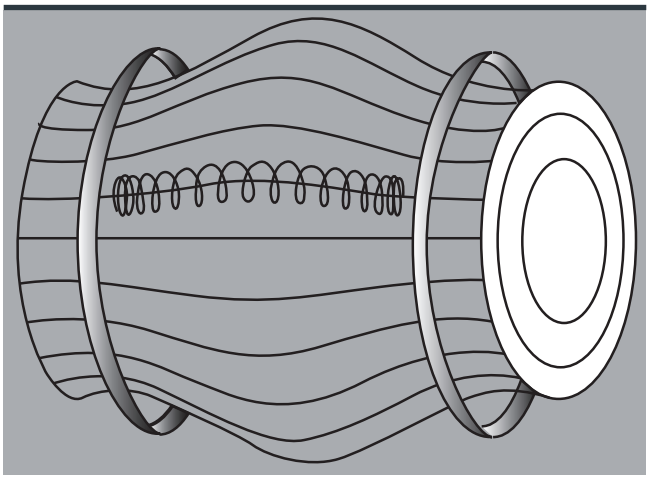
The aim of controlled fusion is presently to build a reactor in which the fusion reaction is the least difficult one to accomplish on earth: ${}^2_1D+{}^3_1T\rightarrow{}^4_2He(3.6MeV)+{}^1_0n(14MeV)$ in a plasma at a temperature of ~ 150 million K. Initially, however, due to their attractive features concerning neutrons and fuel breeding, the $D+D$, and over some period even the $D+{}^3He$ reactions were considered.

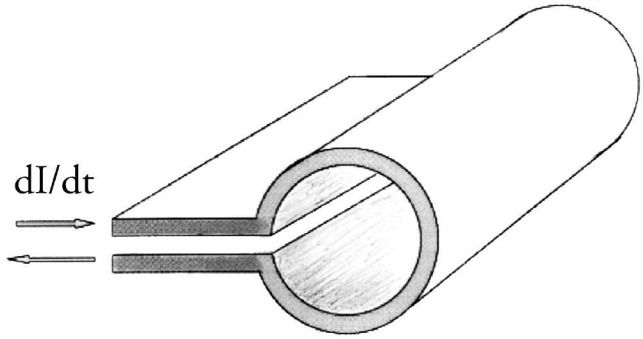
From 1958 until 1980

After the Treaty establishing the European Coal and Steel Community (ECSC - 1951), the Treaty of Rome (1957) established both the Common Market (the European Economic Community - EEC) and the European Atomic Energy Community (EURATOM) of which the development of controlled nuclear fusion has become a major component.

How did this evolve? The Directorate for Fusion in the European Commission was established in 1958 in the wake of the 1958 Geneva conference. The first association between the Euratom Commission and an EU Member State was established in 1959 with the French CEA, soon to be followed by associations with the Italian ENEA, the German laboratories of the Max Planck Institute for Plasma Physics in Garching (Munich) and the Institute for Plasma Physics of the KFA (now FZJ) in •••

▼ FIG. 1: The plasma is trapped between the magnetic mirrors created by a set of two Helmholtz coils. Since the magnetic moment $^1/_2mv_\perp^2/B$ is an adiabatic constant of motion of each charged particle together with the constant sum $^1/_2mv^2$ of the parallel $^1/_2mv_{//}^2$ and perpendicular $^1/_2mv_\perp^2$ kinetic energies, it is clear that particles having at the central plane O, $v_{0\perp}^2/v_0^2-v_{0\perp}^2 < B_{min}/B_{max}$ will escape with a non-zero $^1/_2mv_{//}^2$ through the bottleneck of the magnetic field. The remaining trapped particles are characterised by an asymmetric velocity distribution.





▲ **FIG. 2:** Scheme of a linear theta-pinch coil. A fast inductance one-loop coil is used for creating a fast (μ sec) rising strong magnetic field – maintained at peak value – to compress, heat and transiently confine a hot and dense plasma, whose pressure approaches the pressure of the magnetic field.

··· Jülich, and the Dutch FOM. The Belgian State founded a Euratom association in 1968. The 1970s witnessed the further birth of new associations in the UK and, through special treaties with the EU, in Switzerland and in Sweden. 1972 saw the beginning of the planning of the at present still largest machine in the world, namely the Joint European Torus (JET), as a Joint Undertaking of all Euratom countries, with construction decided in 1977. Since then, together with the gradual extension of the EU, many other Euratom associations were formed and in 2007 we have 26.

While describing the EU fusion situation, we must of course stress that the progress in fusion research occurred on a worldwide scale. Initially, cooperation and exchange of personnel between the individual European laboratories and both the leading US laboratories and the UKAEA Culham laboratory prevailed because of the advanced status of the latter. The role of Europe has become increasingly prominent over the decades and this has finally led to the forthcoming international research fusion reactor ITER being built in Europe (Cadarache, France).

What was the picture of world-controlled fusion research at the inception of the Euratom programme? The initial excitement caused by the Geneva conference and by the premature announcement in 1959 of the production of thermonuclear neutrons on ZETA (UK) gave way gradually to more sober views as was already apparent in the Salzburg IAEA Conference in 1961. The world-wide research remained in a broad exploratory phase in the 1960s. While originally colliding beams, beam-target reactions and even the acceleration of micro-pellets had also been considered, and while the concepts of inertial fusion were mostly not yet considered promising because of missing driver technologies, it had soon become clear that only the use of magnetic fields and of suitable magnetic field configurations could solve the task of sufficiently confining the required hot plasmas. Thus the main emphasis was on trying to understand the physics of magnetic mirrors, pinches of several kinds and of different toroidal configurations.

Let us briefly characterise a magnetic mirror machine, one version of pinches, a tokamak and a stellarator. In each device the hot electrons and ions are confined in a magnetic configuration with a characteristic confinement time τ_E for the energy.

1. A simple linear device is the magnetic mirror (Fig. 1).
2. The Theta pinch (Fig. 2), for which a huge, low inductance capacitor bank is discharged within microseconds into a broad one-loop coil and short-circuited *(crow-bar)* at peak-current.

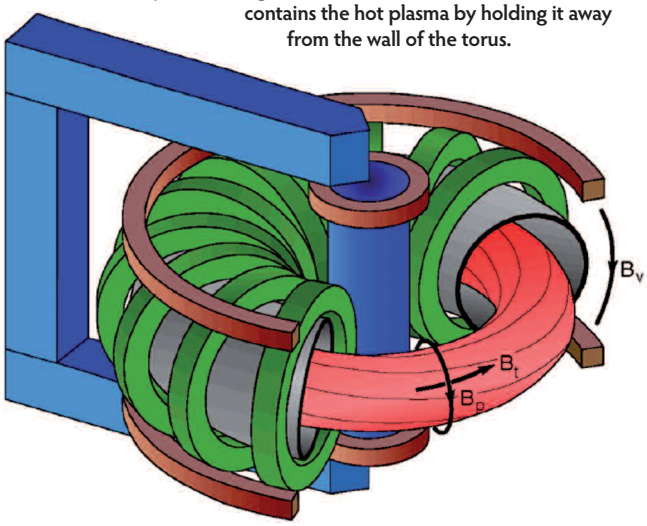
There are two main toroidal devices:

3. The tokamak (Fig. 3) in which the toroidal magnetic field is created by outer magnetic coils while the poloidal magnetic field is created by an induced toroidal current in the plasma, which has a very high conductivity. A key feature is its basic toroidal symmetry.
4. The stellarator (Fig. 4) does not depend on an induced toroidal plasma current. Both the toroidal and poloidal magnetic fields are created by appropriately shaped external coils. This means, however, that toroidal symmetry cannot be maintained.

Let us first address pinches. Due to their straightforward technology, a large part of the worldwide effort of that time was devoted to the study of pinches of several kinds (including plasma focus machines as a special type). Energy stored in capacitor banks (up to the MJ-scale!) was released and focused into a relatively small volume via collectors to build up high magnetic fields in a time scale smaller than microseconds; hot and dense plasmas were created by shock-heating and magnetic compression. While most pinch-types suffered strongly from hydro-magnetic instabilities, the so-called Theta-Pinch turned out to be the least vulnerable in that respect: at the end of the 1960s, very high temperatures had been reached. Despite their success in creating and studying hot plasmas, heat conduction to and outflow through the ends provided, however, no chance to even slightly come close to the desired plasma confinement time.

Also the attempts to avoid the ends and develop toroidal concepts based on pinch-type discharges were not successful and abandoned during the 1970s, though one principle provided an

▼ **FIG. 3:** Schematic diagram of a tokamak. An axial toroidal magnetic field B_t is created by the green coils. The primary of the large transformer induces an axial toroidal current in the plasma acting as the secondary of the transformer. This plasma current creates a poloidal magnetic field B_p perpendicular to it. The combination of the axial toroidal and poloidal magnetic fields is a helical toroidal field which contains the hot plasma by holding it away from the wall of the torus.



essential element for the present advanced Stellarator configuration. Only one special branch of this family, the so-called Reversed Field Pinch (RFP), evolving from a quiescent plasma phase of the abovementioned ZETA-experiment, appeared promising enough to be still studied today.

How did the mirrors fare? The basic magneto-hydrodynamic instability of the early devices was overcome by abandoning the rotational symmetry. Although very high temperatures have been reached, their main problem is the end-losses, because Coulomb-collisions and other processes destroy the required anisotropy of the ion-population. Despite worldwide efforts to invent ever more sophisticated types of end-plugs, this approach was considered, in the EU, as not promising enough and dropped around the mid 70s.

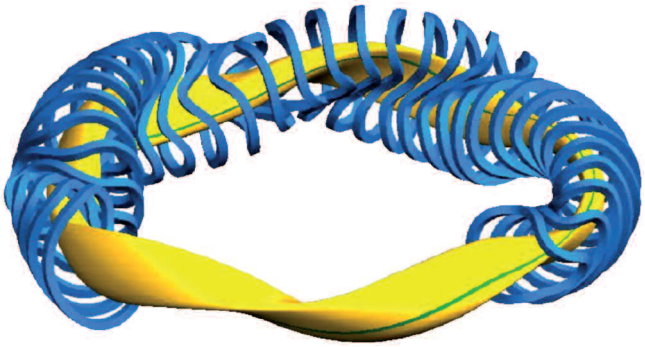
Apart from many insights into the behaviour of relevant high-temperature plasma physics and apart from the development of magnet technology, the above work is an important part of the necessary and continuing learning process on the way to an extremely demanding goal.

Let us now address the fate of the remaining two toroidal concepts. Until 1965, with the Princeton C-Stellarator being the flag-ship, the observed energy and particle confinement were Bohm-like [2]. It was during the 1965 Culham conference that the first results indicating energy confinement times τ_E better than Bohm were reported in some machines but they were met with considerable scepticism.

It was therefore a big surprise when at the 1968 Novosibirsk conference the Kurchatov team of the tokamak T3 reported an energy confinement time τ_E greater by a factor of 50 than that resulting from Bohm-diffusion and an electron temperature T_e of 1000 eV [3]. Artsimovitch, proposed an empirical scaling law $\tau_E \propto na^2T^{3/2}$ indicating that it was not Bohm-like at all. Some other machines also reported a better than Bohm behaviour. In 1969 the Thomson scattering measurements of T_e on T3 by the Culham team lifted the remaining doubts concerning the achieved electron temperature and, together with Artsimovitch's visit to Western Europe and the USA, led to a reassessment of toroidal confinement in the western world.

The ensuing reappraisal took a couple of years; fusion research then became gradually centred on tokamaks (immediately 3 medium-sized ones in Germany, France and Italy and about 100 machines of different sizes were built in the world over three decades). Record temperatures were obtained in the mid-1970s on the French TFR. The Stellarator activity continued on a smaller scale as a generic line on a few machines in Garching, Culham, Japan, USSR and Madison and is now undergoing, since the 90s, a revival linked to significant conceptual progress.

The 1960s and 1970s saw considerable progress in fusion theory (the Pfirsch-Schlüter diffusion, neoclassical theory, magneto-hydrodynamic phenomena – MHD, *etc.*) but, as we know today, the basically anomalous transport – though lower than the originally reported Bohm-level – has not yet been satisfactorily explained, though it is mainly attributed to turbulent processes. It has to be accepted that transport in a fluid as complex as a strongly turbulent magnetized plasma with its long-range electric and magnetic forces is not yet completely understood after



▲ **FIG. 4: Schematic representation of the plasma and of the outer magnetic coils of the stellarator W7-X being built at the Greifswald site of the Max Planck Institute for Plasma Physics.**

decades of intense research. Though the theoretical description of fusion plasma turbulence has made tremendous progress, it has so far been unable to quantitatively predict the performances of fusion plasma machines on general grounds. Thus one has to rely on increasingly more sophisticated and experimentally underpinned empirical scaling laws, and on specialized theoretical and empirical models in order to extrapolate towards the performances of new and larger machines.

As soon as the first confirmations of the promise of tokamaks were being obtained on western tokamaks, further proposals emerged and decisions to accelerate the development were taken. More importantly, the fusion-community felt that time had come to take more daring steps: decisions were taken to build 3 very large tokamaks (TFTR, Princeton 1974; JET, Culham-Oxford 1977; JT60, Tokai 1977). These devices were commissioned in 1982, 1983 and 1985, respectively. When TFTR was closed in 1997, D-III-D in San Diego became the USA's largest tokamak. The EU machine JET (the Joint European Torus, Fig. 5) was built as a Euratom Joint Undertaking, which brought together all the European Associations including the Swiss one. The aim was to approach the $Q = P_{fusion}/P_{heating} = 1$ landmark, *i.e.* a breakeven between the produced fusion power and the invested heating power of a D-T plasma. This is generally considered as a benchmark for the scientific feasibility of controlled magnetic fusion. JET is the largest in the world, and the first machine with a D-shaped cross-section and a flexibility which has enabled a set of significant up grades. It has brought and is still bringing a wealth of important results which were essential for the design of ITER and its future operation. Among these can be highlighted the first controlled D-T production of fusion energy in 1991 and in 1997 of 16 MW corresponding to a Q near to 1.

The fact that the European planning of JET had started in the early 1970s is a proof of the strong ties which have been established between the different national Euratom Associations. These resulted from both the creative and coordinated efforts – in a spirit of competition and cooperation – of a large community of researchers and the enlightened leadership from 1958 until 1986 of the then EU director of Fusion, Prof. Donato •••

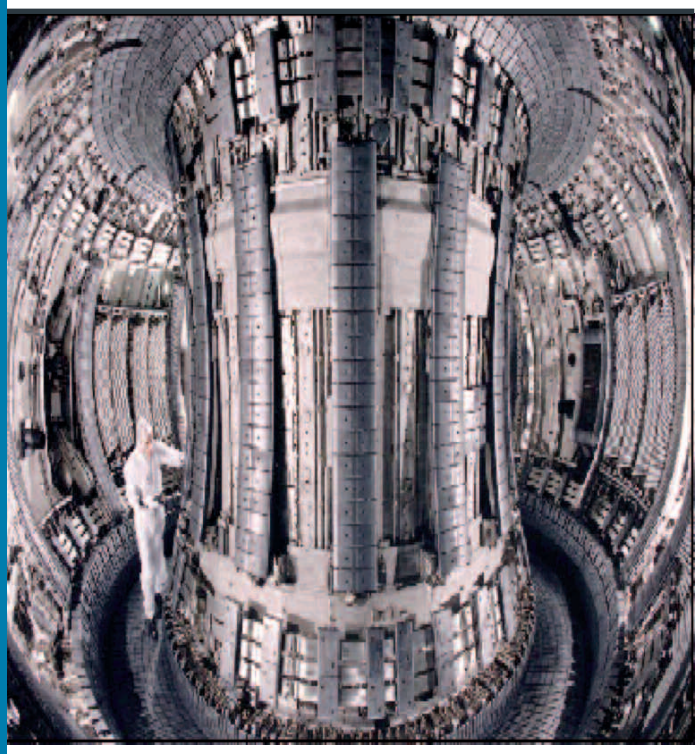
••• Palumbo, the father figure of European fusion. The strength of EU fusion, already apparent in the 1970s, is thus the result of the fact that it formed a coherent European research programme with a long-term strategy relying on the steady national and EU financing embodied in successive four or five years programmes. Up to 2007, the EU provided about 40% of the financial resources (the balance coming from national contributions). The long term strategy leading to the demonstration prototype fusion reactor is summarized in Fig. 6.

From 1980 onwards

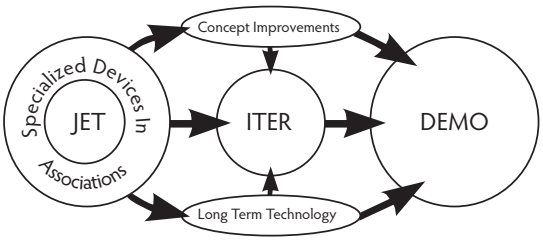
Up to the end of the seventies the tokamak plasma was solely heated by the Ohm resistance of the plasma current. However this only brings the temperature up to 20 to 30 million K because the resistivity of the plasma decreases when T increases and the hope to boost Ohmic-heating by using high-field tokamaks has led to disappointment.

This is why strong "additional" or "auxiliary" heating in the MW range became required. Several methods exist: (i) Neutral beam heating in which ions accelerated up to ~ 140 keV are neutralized before entering the machine where the neutral atoms collide with the plasma, are ionised and impart their energy to the ions and electrons; (ii) Radio-frequency heating at approximately the characteristic ion cyclotron frequency (ICR) or at the electron cyclotron frequency (ECR), or at the hybrid electron-ion frequency (LH). Many European laboratories are among those that developed these demanding and very sophisticated methods for heating hot non-uniform magnetised plasmas. From the end of the 1970s onwards, these auxiliary heating methods were progressively applied and are still being considerably improved.

▼ **FIG. 5:** The Joint European Torus (JET)



R&D Path Towards the first Electricity Producing Reactor (Demo)



▲ **FIG. 6:** Schematic representation of the scientific strategy of the controlled fusion programme of the European Union in going from the present situation to the demonstration reactor.

However, in 1980, a degradation of confinement was observed with increasing heating power and resulted again in serious disappointment. Instead of the encouraging simple scaling law $\tau_E \propto na^2$ valid for ohmically heated plasmas – up to a certain range of $\bar{n}$ (where $\bar{n}$ is the average density and a is the minor radius of the plasma torus) – much more sophisticated scaling laws have now emerged encompassing large data bases (with very different machine sizes, magnetic fields, currents, heating powers, temperatures, etc.). These showed that very large-sized machines would be required to reach the burning process of a fusion plasma.

In addition to the heating and confinement issue, one well-known question was how to cope with the exhaust of power and particles and their interaction with the wall. While so far mainly metal limiters had been used for delineating the outer boundary of the plasma torus, the idea – first implemented in the C-Stellarator – of using a "magnetic divertor" for the exhaust of particles, led, among others, to the design of the Garching ASDEX (axis-symmetric-divertor) tokamak. On this machine, a new confinement regime was discovered in 1982 when the heating reached a certain threshold. This new H-mode is characterised by the establishment of a confinement barrier at the edge zone of the plasma leading to an improved confinement by about a factor two; other more inner modes have been discovered since.

The above indicates how different the physical picture of fusion had become between 1978 and 1988 when – following the preceding European studies on the "Next European Torus" (NET) – the ITER concept was launched as a result of a political initiative of Gorbachev, Mitterand and Reagan. The International Thermonuclear Experimental Reactor (ITER) is an experimental reactor aimed at demonstrating the feasibility of fusion power. It is designed up to its detailed engineering phase (including prototypes of its main components) and its building preparation phase has started in Europe (Cadarache, France) in 2006. A more in depth analysis of ITER is given below. The impressive progress of tokamaks performance is shown (Fig. 7) where the figure of merit $nT\tau_E$ (n: density, T: temperature) product of plasma pressure and confinement time, expressed in atm-s, is displayed as a function of T. Between 1968 and 1991,

this figure of merit was increased by ~ 25 000 and is now only a factor of 6 away from that required for reactor operation. In parallel, not evident from this figure, even greater progress has been made in the achieved lifetime [4] of the plasmas. While in the early 1960s, with the pinches, the lifetime was limited to microseconds, fusion plasmas now exist for seconds to many minutes, with some parameters approaching steady state operation! Finally, we also have to underline the importance of many discoveries, findings and experiments made on smaller machines of the balanced Euratom programme, which were then successfully applied to the largest machines of the world programme. These range from important physical effects and the development of new diagnostic techniques to the appropriate treatment and material choice of the inner wall of the toroidal chamber and developments in engineering plasma physics. In particular, the huge progress in auxiliary heating and diagnostics needs to be emphasized, the latter being for measurements of ion and electron temperatures, density, impurities, fluxes, inner magnetic fields and islands, pressure, etc.

ITER

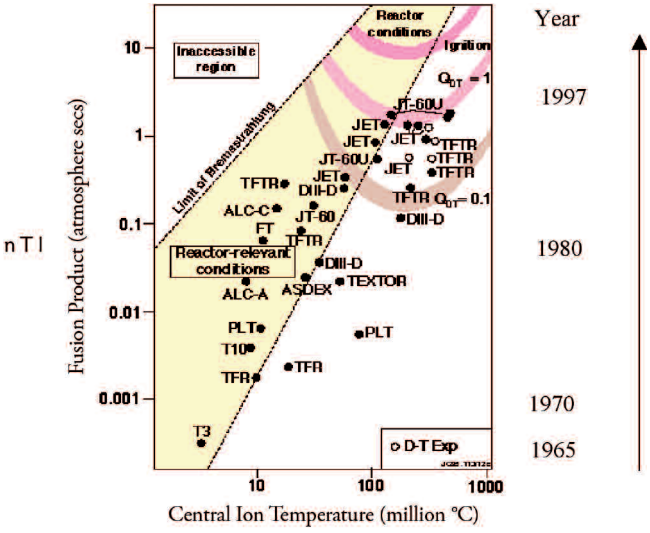
As indicated above, the EU launched in 1983 the studies of an ambitious machine, NET (Next European Torus), which led in 1988 to a possible fusion power-producing machine with dimensions, magnetic field and plasma current rather close to those of the final ITER adopted in 2001. But this remained a reserve option for Europe because the conceptual design activity (CDA) of ITER was launched in 1988 by the EU, Japan, USA and USSR. ITER initially meant the International Tokamak Experimental Reactor but now designates the "way" (to fusion) in Latin.

The CDA was completed in December 1990. The auspices of the International Atomic Energy Agency (IAEA) offered the opportunity of pooling the scientific experience and technological expertise of the world's leading fusion programmes with the following mission for ITER:

1. demonstrate the feasibility of controlled ignition and extended burn in D-T plasmas with steady state as the ultimate goal;
2. demonstrate technologies essential to a reactor in an integrated system (superconducting magnets, remote-handling, etc.);
3. have integrated testing of high heat flux and nuclear components required to utilize fusion power for practical purposes.

The six-year long Engineering Design Activities (EDA) started in July 1992. The Parties produced a detailed, complete and fully integrated design together with all technical data necessary for the construction of a 1.5 GW ITER. The ITER Final Design Report, Cost Review and Safety Analysis were approved by the ITER Council in June 1998. Although the estimated cost for this ITER remained within the initially foreseen financial envelop, the political and financial situation led the Parties to investigate whether, with reduced technical aims and margins but keeping the same strategic aims, it was possible to bring down the cost by approximately 50 %. So, within another 3 years, a detailed engineering design of this reduced-cost ITER was produced.

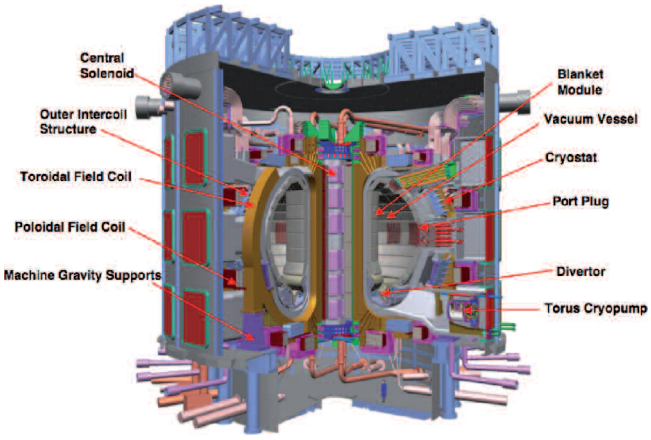
However, for the present smaller ITER the task remains to be the single step before building a demonstration fusion reactor (DEMO) producing electricity. But the decrease in neutron flux and neutron fluence leads to a reduction of the technical potential of the device (e.g. for materials and component testing). This makes it even more mandatory to start the engineering design phase of the International Fusion Materials Irradiation Facility (IFMIF) in order to have a neutron source with a suitable fusion energy spectrum and neutron flux to allow the necessary material tests.



▲ **FIG. 7: The product $nT\tau_E$ versus temperature T (an energy of 1keV corresponds roughly to 10^7 °C) shown as a function of the time of achievement.**

As the USA had temporarily withdrawn from the extended EDA in 1999, the revised Final Design Report (of the 500 MW ITER) was approved by the remaining parties in July 2001. The estimated construction cost is 4.6 G€ at December 2001 prices. The nominal design parameters are : plasma current 15 MA, major radius 6.2 m, minor radius 2.0 m, on-axis toroidal field 5.3 T, plasma elongation at the separatrix 1.85. The whole design is the result of nine years of effort, based on the scientific input from the world-wide fusion programme. The related R&D was mainly centred on seven large R&D projects addressing the key technologies needed. These are: the central solenoid model coil, the toroidal field coil, the vacuum vessel sector, the blanket module, the blanket module remote handling, the divertor cassette and the divertor remote handling. The successful completion of these key test modules gives great confidence in the success of building the whole machine. Fig. 8 displays a cutaway view of ITER.

The resulting negotiations for the building of ITER started in 2001 with Canada as a new member and addressed many aspects such as site, management structure, staff, procurement system and allocation, financial regulations, decommissioning, intellectual property rights and other aspects such as the proper management of the risks.



▲ **FIG. 8:** Cutaway of the ITER Tokamak inside the cryostat/biological shield. The dimensions of the cryostat are 24m. x 28m.

In 2003, the USA decided to rejoin the ITER process, China and South Korea to join and Canada to leave. Two sites, Rokkasho in Japan and Cadarache in Europe (France) remained as candidate sites for ITER. After an agreement between the EU and Japan on a broader approach to fusion, Cadarache was selected as the ITER site in June 2005. The broader approach agreement implies that Japan will be supported in three domains: (1) on the JT60 super upgrade tokamak, (2) in the preparatory work in Rokkasho of the IFMIF and (3) a fusion computer centre in Rokkasho.

The ITER International Fusion Energy Organisation (IIFEO) agreement (see Fig. 9) on ITER was reached in December 2005 and signed in November 2006 by the above stated parties (EU, China, Japan, Russia, South Korea and USA) plus India, the last and seventh partner; this represents more than half of mankind. The financial burden of the construction of ITER is borne by the EU at a level of 45.4 % and by each other partner at a level of 9.1 %.

The different components of ITER are distributed into ~ 85 important packages having each an agreed a priori value. Most of the contributions (~ 85 to 90 %) of the Parties will be "in-kind" and consist in delivering a certain number of these packages, the content of which having been very carefully contractually specified by the IIFEO Central Team.

The nominee Director General of ITER, Dr IKEDA (Japan) was chosen in 2006 together with the nominee Principal Deputy Director General, Dr HOLTKAMP (Germany). The appointment of the key staff and the building up of highly competent and skilled teams is underway. Before issuing the first contracts, a general review of the whole project was finalized at the end of 2007. Extending the phase of negotiations has now put the date of the first plasma around 2017, if no unexpected problems arise. The first phase of operation will be with hydrogen while the D-T operation will be launched some years later.

EU fusion has from the beginning played a major role in the ITER endeavour by providing its international director until 2004, the largest share of manpower and R&D funds, especially during the critical 1995-2001 period, and finally by shouldering nearly half of the construction cost at the European site of Cadarache. Thus one can say that ITER is for the EU a major achievement in its consistent long-term strategy (see Fig. 6) towards harnessing fusion energy as repeated in the preamble to each EU framework programme. Structure and content of the EU fusion programme are addressed in the next section.

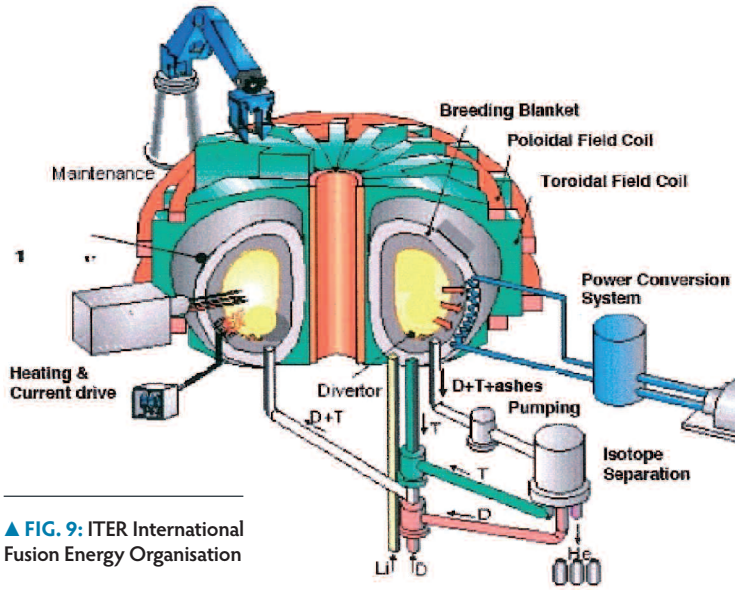
Implementation of the EU Fusion Programme

The principal mechanism used to implement the participation of member states in the European fusion programme is the "Contract of Association". Each state, or organisation within a state, concludes a contract with EURATOM, creating a "Euratom Association". This contract specifies the programme of work to be undertaken by the Association, promotes mutual access to major facilities, and provides the mechanism for funding by EURATOM. For those participants not having concluded a contract of Association, contracts of limited duration for specific purposes are installed. In addition a number of technological developments are pursued through contracts with European industry.

Some of the Associations have large-scale experimental facilities, while the smaller Associations generally have more limited facilities. The rules for awarding preferential support [5] encourage the smaller Associations to participate in the larger experiments, for example by developing, installing and exploiting auxiliary instrumentation. Collaboration is further promoted by financial support to assist the exchange of personnel. Training and mobility of young researchers is also supported by EU Fellowships.

The active collaboration between the European Commission and the Member states and Associations is ensured through the Euratom Consultative Committee for fusion and a set of relevant agreements and committees.

The total effort in the Community fusion programme is equivalent to about 2000 professionals and expenditure from all sources is about 450-500 M€ per year. Of this, about 190



▲ **FIG. 9:** ITER International Fusion Energy Organisation

M€ per year come from the EU Euratom budget (750 M€ in total over 4 years from the FP 6 budget plus a small supplement for the candidate EU States). Since the inception of FP 7 (2007-2011) and the start of the building of ITER, the EU fusion budget has risen to 1 947 M€ of which at least 900 M€ are for the Associations and JET.

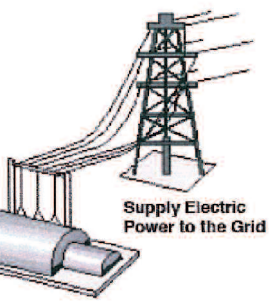
Towards fusion energy and final remarks

When in the early 1950s, the first ideas for the peaceful use of fusion energy emerged, society was already well aware of the finite nature of fossil fuel resources, and both fission and fusion development were supported in view of a future with dwindling resources. During the following decades, however, no public awareness existed yet about the greenhouse effect and its consequences on the global climate, and cheap oil – despite the first 1973 oil crisis – postponed the looming energy problem into the far future. In that situation, not only was the use of fission energy challenged (and in some countries still is) but also the continuation of the fusion programme with its very long perspective was questioned, not the least because of its so-called everlasting "50-years-horizon" as critics used to point out. Yet the stamina of the fusion community and the wise outcome of the political dispute bridged the crisis: we need to acknowledge the political support required for the decision to construct ITER.

The time has come when energy and climate are now at the top of the world political agenda. Society seems to have gained a deep-rooted understanding of the seriousness of these problems. Scenarios exist which demonstrate the huge supply gap to be expected towards the end of this century. It is obvious now that fusion energy must be developed with the necessary impact to gain its place in the world's energy mix as soon as possible.

In Europe, the Council of Ministers has approved in 2003 the concept of a fast-track approach which envisages the start of the building of the DEMO-Proto reactor around 2025 and, extremely ambitiously, the operation of the first commercial fusion reactors around 2040-2050. Such an agenda will require much determination and effort.

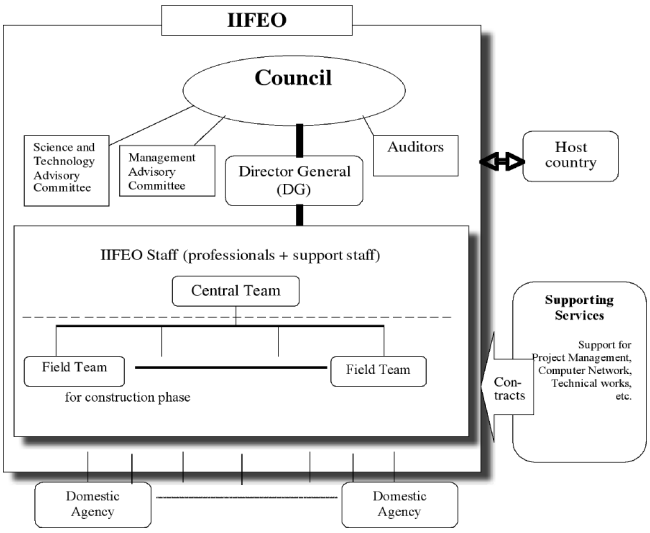
Can this ambitious time-table be achieved? To gauge its feasibility, let us look back at the history of fusion. In 1988, when ITER was launched, Europe was designing its next machine namely NET, the main parameters of which were rather close to the present ones of ITER. Had this machine been built, it would now be operating. Of course, the present ITER embodies the significant advances in physics and technological improvements made since then; it is therefore a better and more modern machine but it is clear that had we had NET, world fusion would be more advanced and we would have won years on the roadmap to fusion energy. Decision makers will therefore have to move faster and provide the necessary means if we want to achieve such a time-table.



In the domain of fusion materials and technology, the preparatory work on IFMIF has started and its construction is foreseen. The development of tritium breeding blankets is underway. Building more than one DEMO-Proto reactor would have a very beneficial influence in trying to keep such a time-table.

What about the price of such a programme? The cost of the construction of ITER is roughly 5 G€ (2001) over 10 years. Yes, this is a large sum, but remains small when compared to our energy bill: ITER is worth less than one day of the world's present oil bill, even if – as might be foreseen – the construction of ITER would reveal unexpected difficulties and the need for more money.

Power-plant conceptual studies of a Tokamak-type fusion reactor (see fig. 10) have been completed by the European fusion programme in 2004 with a team which included economists and nuclear fission engineers. It assessed the safety and environmental impacts together with the economics of a fusion plant. It examined four models ranging from a water-cooled plant using steel (A) to a helium-cooled plant (D) using silicon carbide to allow higher coolant temperatures of up to 1000°C in order to increase the plant efficiency. The costs ranged from 0.05 to 0.09 € per kWh (depending on the maturity of the technology) for A down to 0.03 - 0.05 € for D and this without taking a carbon tax into account. To us, this appears quite acceptable even if it were underestimated. An obvious advantage of fusion is that the "external costs", *i.e.* the impact on health, climate and environment, are essentially zero.



▲ **FIG. 10:** Sketch of a tokamak-type fusion reactor

Let us recall what Bhaba had said in 1955. He was right, because the JET design was presented less than 20 years later, and JET has demonstrated what Bhabha had foreseen. But Post was also right: while physics will also play a very important role in the future, mainly concerning the burn process and basic improvements, the main emphasis – and costs – will be gradually shifted to technology and engineering issues. And it will have taken a century from the start in fusion research until fusion electricity will be fed into the grid on a commercial basis.

Indeed, this will still be an arduous task with many uncertainties to overcome and it requires continuous political support.

Reality is also that the progress achieved in raising the fusion energy multiplication factor Q (Q = Fusion power/External heating power) — from 1/100 000 at the end of the 1960's to the present value of nearly 1 — is truly impressive (and comparable to Moore's celebrated law for the rapid progress of the number of transistors on a chip). ITER will have a Q of the order of 10 or more and thus confirm the scientific and technological feasibility of fusion. Although years would have been gained by more earlier support and less procrastination, the fusion power station is now in 2008 on the horizon.

The seriousness of the energy and climate issue requires that, within the portfolio of energy measures and solutions to be implemented, controlled nuclear fusion must have a distinct place within a proper mix of sustainable energy sources. It is the only one for which the basically inexhaustible fuel (deuterium and lithium) is evenly distributed on earth and thus able to ensure a safe, sustainable, environmentally friendly energy supply. ■

Acknowledgements

We wish to thank Professor Fritz Wagner (Max-Planck Institute, Greifswald, Germany) for his constructive remarks and suggestions.

NOTES

1. *Rev. Mod. Phys.* **28**, 338 (1956).
2. Classical radial diffusion in magnetized (B) cylindrical plasma is characterized by the diffusion coefficient $D \propto T/B^2$ while anomalous Bohm diffusion by $D \propto T/B$, where T is the temperature. Neoclassical diffusion describes classical diffusion corrected for the global effect due to an inhomogeneous curved magnetic field. The Bohm-physics and its consequences are not mentioned.
3. 1eV corresponds to a temperature of 11 000K
4. The lifetime is the time during which a plasma is sustained.
5. The basic general support by Euratom amounted to 25% until FP6 and has now been lowered to 20%. Preferential support is an additional financing of 20% of specially approved capital costs by Euratom.

PHYSICS IN DAILY LIFE: COUNTING FLAMES

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L.J.F. (Jo) Hermans,
Leiden University • The Netherlands • Email: Hermans@Physics.LeidenUniv.nl

Ask any layman this simple question: "If you run your hot-water tap, you are using energy, right? How many lights do you think you could switch on from that energy during the same time?"

The answer will probably be something like: "Well, let's see, I guess 10, or perhaps even 20". He or she will be surprised if we say that it may be as many as 1000.

The layman does not know that the specific heat capacity of water is remarkably high. And he or she does not realize the full extent of the first law of thermodynamics.

For us physicists, it's easy. We could even explain things by counting flames, knowing that a small flame produces about 100 watts. Take a match. Its mass is about 0,1 gram and therefore its wood contains roughly 2 kJ. Now just assume that it burns for about 20 seconds, and there you go: 2000 J / 20 s = 100 W. For a candle we can do the same exercise. Find out for how long it will burn, look up the heat of combustion of paraffin or stearine, and again: about 100 W. So the rule of thumb is simple: a small flame is a heater of about 100 watts.

From here it's downhill. First let us look at a camping gas cooker, or – if we use natural gas at home – at the gas stove. Each burner has 20 to 30 flames, so a burner should produce 2 to 3 kW of heat. And sure enough: if we look it up on the internet, Google tells us that our guess was right. For a hot water tap, though, that is not enough. If we happen to be familiar with gas geysers, we remember that they have about 10 rows of 10 flames. That makes 100 × 100 W or 10 kW. And the gas geyser isn't even a device of great luxury. It has too small a capacity to produce a decent shower, for example. It is therefore safe to assume that an average hot water tap will easily exceed those 10 kW.

But let us not overdo things, and stick to 10 kW. And let us for simplicity assume that the water is heated electrically, so we can directly compare that to electric lighting. An efficient light source producing 600 lumen consumes 11 W. That is, indeed, a factor of 1000 lower than the hot-water tap.

This is a nice little lesson for any layman concerned about energy and global warming. Most often, he or she identifies energy use at home with things that turn or things that shine: electric motors or lighting. Wrong. It's not motion. It's not light. *Heat* is our guide. ■

EXECUTIVE COMMITTEE

President
F. Wagner
Max-Planck-Institut fuer Plasmaphysik
Branch Greifswald
Wendelsteinstrasse 1
DE-17491 Greifswald, Germany
TEL/FAX +49 3834 882001 / +49 3834 882009
EMAIL fritz.wagner@ipp.mpg.de

Vice-President
O. Poulsen
Engineering College of Aarhus
Dalgas avenue 2
DK- 8000 Aarhus C, Denmark
TEL/FAX +45 87 302 600 / +45 21 212 644
EMAIL opo@iha.dk

Secretary
B. Feuerbacher
DLR - German Aerospace Center
Institute of Space Simulation • Postfach 90 60 58
DE-51170 Köln, Germany
TEL/FAX +49 2203 601-2176 / +49 2203 61768
EMAIL berndt.feuerbacher@dlr.de

Treasurer
J. L. Beeby
University of Leicester
University Road 17
Leicester LE1 7RH, United Kingdom
TEL/FAX +44 116 252 3495 / +44 116 252 2770
EMAIL zjb@leicester.ac.uk

Executive Committee Members
A. Di Virgilio
INFN
Largo B. Pontecorvo 3
IT-56127 Pisa, Italy
TEL/FAX +390 - 50 880 352 / +390 - 50 880 350
EMAIL angela.divirgilio@pi.infn.it

K. Hämäläinen
University of Helsinki
Department of Physical Sciences
Division of X-Ray Physics • PO BOX 64
FI-00014 Helsinki, Finland
TEL/FAX +358 9 191 50640 / +358 9 191 50610
EMAIL Keijo.Hamalainen@helsinki.fi

M. Kolwas
Polish Academy of Sciences
Institute of Physics
International Postgraduate Studies
Al. Lotnikow 32/46
PL-02-668 Warsaw, Poland
TEL/FAX +48 228 470 917 / +48 228 430 926
EMAIL kolwas@ifpan.edu.pl

A.M. Levy
University of Copenhagen
"Det Naturvidenskabelige" Fakultet
Oster Voldgade 3
DK-1350 Copenhagen K., Denmark
TEL/FAX +45 35 324 280/ +45 33 773 820
EMAIL aml@adm.ku.dk

F. Masnou
CNRS
Laboratoire Aimé Cotton
Université Paris-Sud, Bât. 505
91405 Orsay Cedex, France
TEL/FAX +33 1 69352052 / +33 1 69352100
EMAIL francoise.masnou@lac.u-psud.fr

V. Urumov
Faculty of Natural Sciences and Mathematics
Institute of Physics
PO BOX 162
MK – Skopje, Macedonia
TEL +389 2 31 17 055 (Ext : 318)
FAX +389 2 32 28 141
EMAIL urumov@iunona.pmf.ukim.edu.mk

V. R. Velasco
Instituto de Ciencias de Materiales de Madrid – CSIC
Sor Juana Inés de la Cruz 3 (Cantoblanco)
ES-28049 Madrid, Spain
TEL/FAX +34 91 334 90 45 / +34 91 372 06 23
EMAIL vrvr@icmm.csic.es

The Secretary General is a member of the Executive Committee and most Committees *ex officio* (*i.e.* by virtue of his office).

SECRETARIAT

European Physical Society
6 rue des Frères Lumière • BP 2136
FR-68060 Mulhouse Cedex, France
TEL/FAX +33 389 329 440 / +33 389 329 449

Secretary General
David Lee • **EMAIL** d.lee@eps.org

Administrative Secretary
Sylvie Loskill • **EMAIL** s.loskill@eps.org

Conferences
Patricia Helfenstein • **EMAIL** p.helfenstein@eps.org

Graphic Designer
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Project Leader EPS Services
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17 avenue du Hoggar • BP 112
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Production Manager
Agnes Henri
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Advertising
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EMAIL boulven@edpsciences.org

COUNCIL

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M. Benedict
University of Szeged
Tisza l. krt. 84-86
HU-6720 Szeged, Hungary
TEL/FAX +36 62 544 368
EMAIL benedict@physx.u-szeged.hu

V. Malka
Lab. d'Optique Appliquée (LOA)Ecole Polytechnique
Chemin de la hunière
FR-91761 Palaiseau cedex
TEL/FAX +33 169 319 903 / +33 169 319 996
EMAIL victor.malka@ensta.fr

F. Schwabl
Technische Universität München • Physik Department
james-franck-str.
DE-85747 Garching, Germany
TEL/FAX +49 8 928 912 361 / +49 8 928 914 641
EMAIL schwabl@ph.tum.de

J. Meyer-Ter-Vehn
Max-Planck-Institut fuer Quantenoptik
Hans-Kopfermann-Str. 1
DE-85748 Garching, Germany
TEL/FAX +49 89 32905 137 / +49 89 32905 200
EMAIL meyer-ter-vehn@mpq.mpg.de

P. Weightman
University of Liverpool • Physics Department
Surface Science Research Centre
Oxford Street
Liverpool L69 3BX, United Kingdom
TEL/FAX +44 151 794 3871 / +44 151 794 3441
EMAIL peterw@liv.ac.uk

Associate Members Delegates
N. Brookes
ESRF • BP220
F-38043 Grenoble, France
TEL +33 (0)4 76 88 24 39 (office)
+33 (0)4 76 88 22 00 (beam line)
FAX +33 (0)4 76 88 21 60
EMAIL brooks@esrf.fr

E. Elsen
DESY
Notkestr. 85
DE-22603 Hamburg, Germany
TEL/FAX +49 4 089 982 565 / +49 4 089 983 093
EMAIL eckhard.elsen@desy.de

M.Giorgi
INFN - Sezione di Pisa and SLAC
Largo B. Pontecorvo, 3
IT-56127 Pisa, Italy
TEL/FAX + 39 050 221 4281 / + 39 050 221 4317
EMAIL marcello.giorgi@df.infn.it;
giorgi@slac.stanford.edu

J. Mesot
Laboratory for Neutron Scattering
ETH-Zurich and Paul Scherrer Institute
CH-5232 Villigen, PSI, Switzerland
TEL/FAX +41 56 310 4029 / +41 56 310 2939
EMAIL joel.mesot@psi.ch

A. Schopper
CERN – EP Division
CH-1211 Geneva 23, Switzerland
TEL/FAX +41 22 76 73158 / +41 22 767 87 60
EMAIL Andreas.Schopper@cern.ch

HONORARY MEMBERS

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Chair O. Scholten
Kernfysisch Versneller Instituut (KVI)
Zernikelaan, 25
NL-747 AA Groningen, The Netherlands
TEL/FAX +31 50 363 3552 / +31 50 363 4003
EMAIL scholten@kvi.nl

East-West Task Force

President J. Nadrchal
Academy of Sciences of the Czech Republic
Institute of Physics
Cukrovarnicka 10
CZ-162 53 Prague 6, Czech Republic
TEL/FAX +420 220 513 411 / +420 233 543 184
EMAIL nadrchal@fzu.cz

Gender Equality in Physics

Chair G. Gehring
University of Sheffield
Department of Physics & Astronomy • Hicks Building
UK-S3 7RH Sheffield, United Kingdom
TEL/FAX +44 1 142 224 299 / +44 1 142 223 555
EMAIL g.gehring@sheffield.ac.uk

Grants Committee

Chair O. Scholten
Kernfysisch Versneller instituut (KVi)
Zernikelaan, 25
nl-747 aa Groningen, the netherlands
TEL/FAX +31 50 363 3552 / +31 50 363 4003
EMAIL scholten@kvi.nl

Mobility Committee

Chair I. Sosnowska
University of Warsaw • Wydzial Fizyki
Ul. hoza 69
PL-00681 Warsaw, Poland
TEL/FAX +48 226 287 262 / +48 226 287 252
EMAIL izabela@fuw.edu.pl

Publications Committee

Chair O. Poulsen
Engineering College of Aarhus
Dalgas avenue 2
DK- 8000 Aarhus C, Denmark
TEL/FAX +45 87 302 600 / +45 21 212 644
EMAIL opo@iha.dk

DIVISIONS & SECTIONS

Astrophysics

Chair A.M. Cruise
The University of Birmingham • Edgbaston
UK-B15 2TT Birmingham, United Kingdom
TEL/FAX +44 1 214 143 978 / +44 1 214 144 534
EMAIL a.m.cruise@bham.ac.uk

Sections
Gravitational Physics Section
Solar Physics Section

Atomic & Molecular Physics

Chair H. Cederquist
AlbaNova University Center • Physics Department
Stockholm University
SE-106 91 Stockholm, Sweden
TEL/FAX + 46 8 55 37 8626 / + 46 8 55 37 8601
EMAIL cederquist@physto.se

Sections
Atomic Spectroscopy Section (EGAS)
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Condensed Matter Division

Chair E.P. O'Reilly
Tyndall National Institute (NMRC)
Lee maltings, Prospect Row
IE-Cork, Ireland
TEL/FAX +353 214 904 413 / +353 214 270 271
EMAIL eoin.oreilly@nmrc.ie; eoin.oreilly@tyndall.ie

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Education

Chair E. Johansson
Stockholm University, Department of Physics
AlbaNova University Centre
SE-106 91 Stockholm, Sweden
TEL/FAX +46 855 378 670 / +46 855 378 601
EMAIL kej@physto.se

Environmental Physics

Chair A. Goede
FOM • Institute for Plasma Physics • PO Box 1207
NL-3430 BE Nieuwegein, The Netherlands
TEL/FAX +31 30 609 6955 / +31 30 603 1204
EMAIL a.p.h.goede@rijnhuizen.nl

High Energy & Particle Physics

Chair P. Osland
Department of Physics And Technology
University Of Bergen
Allegaten 55 • NO-5007 Bergen, Norway
TEL/FAX +47 (5) 212768
EMAIL Per.Osland@ift.uib.no

Nuclear Physics

Chair H. Freiesleben
Institut für Kern- und Teilchenphysik
Technische Universität Dresden
Mommsensträsse 13
DE-01069 Dresden, Germany
TEL/FAX +49 (0)351 46 35461 / +49 (0)351 4633 7292
EMAIL freiesleben@physik.tu-dresden.de

Physics in Life Sciences

Chair P.A. Lindgård
Technical University of Denmark (DTU)
Materials Research Department • Blg. 309
DK-2800 Lyngby, Denmark
TEL/FAX +49 (0)351 46 35461 / +49 (0)351 4633 7292
EMAIL p.a.lindgard@risoe.dk

Plasma Physics

Chair J.B Lister
CRPP / EPFL
CH-1015 Lausanne, Switzerland
TEL/FAX +41 216 933 405 / +41 216 935 176
EMAIL jo.lister@epfl.ch

Sections
Beam Plasma and Inertial Fusion Section
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Chair G. Björk
Royal Institute of Technology
Department of Electronics • K T H Electrum 229
SE-164 40 Kista, Sweden
TEL/FAX +46 8 7521282 / +46 8 7521240
EMAIL gunnarb@imit.kth.se

Statistical & Nonlinear Physics

Chair J.-P. Boon
Local 2.N5.215, CP 231 • ULB Campus Plaine
BE-1050 Bruxelles, Belgium
TEL/FAX +32 26 505 527 / +32 26 505 767
EMAIL jpboon@ulb.ac.b

GROUPS

Accelerators Group

Chair C. Biscari
LNF-INFN - Via Enrico Fermi 40
IT-0044 Frascati (Roma), Italy
EMAIL caterina.biscari@lnf.infn.it

Computational Physics Group

Chair P.H. Borcherds
The University of Birmingham • Physics Department
Edgbaston
UK-Birmingham B15 2TT, United Kingdom
TEL/FAX +44 1 214 753 029
EMAIL p.h.borcherds@bham.ac.uk

Experimental Physics Control Systems Group

Chair R. Müller
BESSY Int. • Rudower Chaussee 5 - Geb. 14.51
DE-12489 Berlin, Germany
TEL/FAX +49 30 6392 4849 / +49 30 6392 4632
EMAIL roland.mueller@bessy.de

History of Physics Group

Chair P. Schuster
Oberneuberg 78
AT-8225 Poellauberg, Austria
TEL/FAX +43(0)3335 4850 / +43(0)3335 4851
EMAIL peterschuster@eircom.net

Physics for Development Group

Chair M. Chergui
Laboratoire de Spectroscopie Ultrarapide (LSU), ISIC
Faculté des Sciences de Base, BSP Ecole
Polytechnique Fédérale de Lausanne (EPFL)
CH-1015 Lausanne-Dorigny, Switzerland
TEL/FAX +41 21 693 0457 / +41 21 693 0422
EMAIL majed.chergui@epfl.ch

Technology Group

Chair J. Vaagen
University of Bergen, Department of Physics and
Technology, Allegaten 55
NO-5007 Bergen, Norway
TEL/FAX +47 55 582 724 / +47 55 589 440
EMAIL jans.vaagen@fi.uib.no

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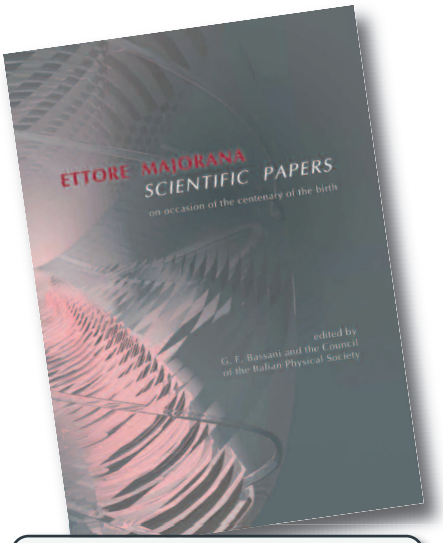
ETTORE MAJORANA , SCIENTIFIC PAPERS



F. Bassani Giuseppe,
SIF Edizioni Scientifiche, 2006, 320 pp.,
ISBN 8874380313

This book consists in the reproduction of the nine scientific papers written by Ettore Majorana in his short life, together with another paper and the introduction of the inaugural lecture given by him at the beginning of the year 1938 at the University of Naples, published after his death. It is interesting to note that all original papers are in Italian apart from one, in the *Zetschrift fur Physik*, which is in German. To each of them is appended the English translation and a detailed comment by a present expert in the field.

It is indeed a source of surprise and admiration that these papers cover, with great versatility, different fields and that most of them have a considerable impact even today in these present subjects of our science. For this reason I particularly appreciate the accompanying comments which not only bring us from the brilliant original ideas, now more that 70 years old, to the present scientific status of each discipline, but also allow us to feel the scientific environment of those times.

The two notes on the first paper, presented here with comments by E.Arimondo, F.Guerra and N.Robotti, deal with an improved evaluation of Rydberg terms in neutral and positively ionized atoms. These searches were partly carried out by Majorana when he was still a student under the leadership of Enrico Fermi and led to results obtained in parallel by L.H. Thomas.

Most of the papers, from two to seven deal with atomic and molecular physics, with comments by E. Sasso, M. Inguscio, F. Minardi and E. Arimondo. They refer to detailed calculations of Helium and to the related study of pseudo-polar reactions of hydrogen atoms, on the anomalous triplets of tin, cadmium and mercury. and on the processes involving oriented atoms in a variable magnetic field.

Paper 7 on the relativistic theory of particles with arbitrary intrinsic angular momentum could appear obsolete now, but, as pointed out by N.Cabibbo, could reappear in modern string theory..

Paper 8 commented on by L.A.Radicati di Brozolo is the only one dealing with low energy nuclear physics and is a consequence of the friendly collaboration with W.Heisenberg in Leipzig. It contains a nuclear model based on exchange forces between protons and neutrons which we could consider a good competitor to the one suggested in those times by Heisenberg himself.

As pointed out by L.Maiani the paper on the symmetric theory of electrons and positron has an extraordinary impact on the fundamental physics of neutrinos. Undoubtedly the name of Ettore Majorana was never scientifically quoted as in these last years. This theory leads to the famous puzzle: is the neutrino a Dirac or a Majorana particle? The second hypothesis implies substantially a neutrino with a finite mass, which is suggested by the recent results of neutrino and antineutrino oscillations. It presently stimulates all over the world a great number of experiments to ascertain the nature of the neutrino and determine its mass.

Two papers have been published after the disappearance of Ettore Majorana : an unusual paper, commented on by R.N. Mantegna, refers to the application of the statistical laws of physics to sociology, while the second is a brief , but clear and very interesting introduction to modern physics commented by B.Preziosi and E.Recami.

In conclusion reading this book is a continuous source of surprise and admiration for this exceptional physicist who in his short, and probably tragic, life has been able to produce so many brilliant ideas of great impact even today. ■

Ettore Fiorini
Universita' di Milano-Bicocca, Milano, Italy