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Fermionic atoms in an optical lattice
The origin of the Earth's magnetic field
CP violation in weak decays of neutral K mesons
Physics in daily life: Cycling in the wind
An interview with Sir Anthony Leggett

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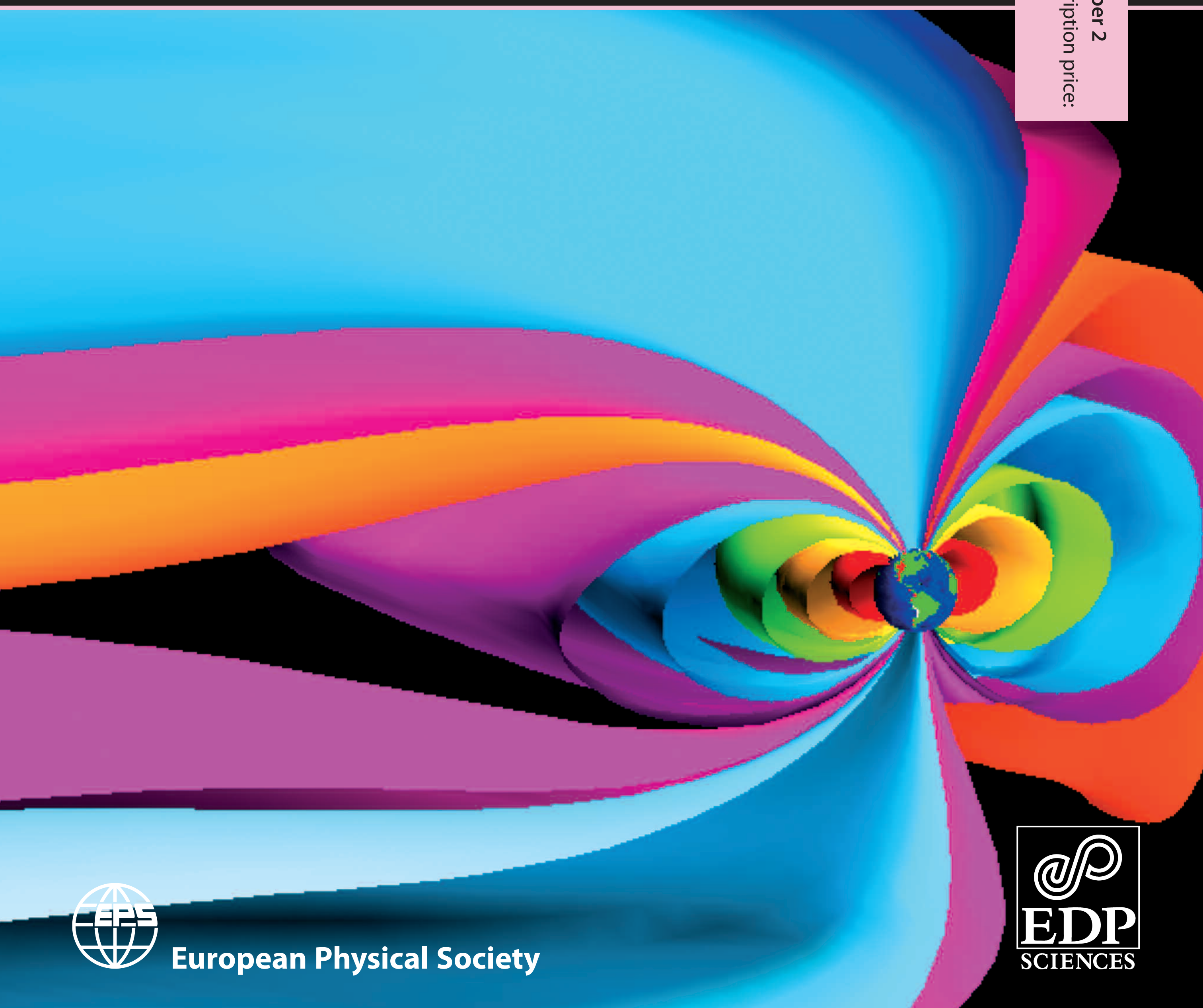

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cover picture: © CNRS Photothèque - ROBERT Patrick
Laboratory: CETP, Velizy, Velizy Villacoublay.
Three-dimensional representation of the Terrestrial magnetic field, according to the model of Tsyganenko 87. The magnetic field is visualized in the form of "magnetic shells" of which the feet of the tension fields on the surface of the Earth have the same magnetic latitude. The sun is on the right.

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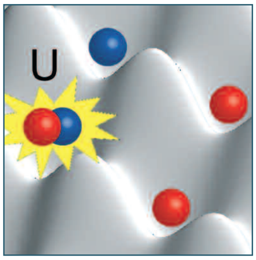
Highlights: transportation of nitrogen atoms



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Physics in Europe

There are two different views of physics in Europe. Both views are correct, but together they point to problems in realizing a stronger future for physics in our part of the world. The first view is derived from one of great strengths. European physicists are productive, they write state-of-the-art publications and they publish more and more quality work in refereed journals. On a global scale Europe is a stronghold for physics research, that matches the best in the world. Moreover, successful EU research programs have made it possible to offer talented young physicists, from Europe and elsewhere, career possibilities in Europe.

We note that a new funding body, the European Research Council (ERC) is being formed to take up the challenge to support the very best of science in Europe, albeit 50 years after the foundation of NSF in the US. The ERC is a most welcome addition to European funding bodies, composed of strong national agencies and growing European Union catalyzed actions. So what is wrong with this picture? As far as it goes, it is very optimistic for European science, but it only presents one side of the coin.

The other side tells a different story. European science is fragmented particularly in its communication channels with too many small conferences with only limited visibility outside their particular field and a publication industry fighting with strong and high impact US journals which successfully attract a growing number of high quality papers from European authors.

Competition can be viewed as healthy only so long as we maintain balanced relationships. It is, however, well known in industry that a market with no real competition is no market. The weakened nationally flavored European science industry is no match for the strong US science industry. In the US we find strong "continental" conferences (CLEO, DAMOP...) and a powerful publication industry which has successfully penetrated the market to such an extent that academic employment in Europe often is contingent upon publishing therein.

Should we toss the coin and hope for the same (good) side to show up or should we look into measures to make a coin with two strong sides? With regard to conferences, several of the Divisions in EPS have successfully challenged the fragmented model. The Condensed Matter General Conference (CMD), this year in Dresden and the CLEO-Europe meetings in Munich are just two examples of strong European conferences with a clear international appeal. We need more conferences capable of attracting large crowds from around the world and from industry.

Accordingly, more EPS Divisions are looking to revise their conference portfolio with the aim of establishing stronger and internationally more visible conferences. This development is supported by the EPS conference secretariat in Mulhouse. Over the last 5 years this conference secretariat has gained more and more experience and is today a professional organization which can support Divisions and Groups in arranging conferences beyond those of today's smaller topical conferences.

Although there are promising developments in conferences, the situation is more difficult in relation to the fragmentation of the publication business. We find in Europe a wealth of journals, societal journals and commercial journals. EPS is itself a part of this fragmented journal industry, characterized by the desire by each of the publishers to attract the best and hottest papers. Added to this is a strong US publication tradition with a range of high impact journals that attract many of the best European physics papers.

It is my impression that national societies, physics institutes, physicists and libraries around Europe recognize the need for change in order to maintain a strong and powerful European publication industry which maintains its competitive edge. Where are solutions to be found? By using the successful techniques that have been the basis of the strengths of European science, i.e. in cooperation. It is necessary for European publishers to begin speaking with each other. This may mean crossing lines between academic, societal and commercial publishers. Are we able to envisage a new European physics journal platform without bias? A vision which includes a full spectrum of high quality journals, letter journals, review journals and even a strong European physics magazine.

This is by no means a threat to the existing national journals, but it is a strengthened platform to place European physics in a stronger position internationally as well as to give European physics a clearer European face. What has proven to be so difficult for the European Union – to create a cohesive Europe – must not prevent European physicists from trying. In our daily work every physicist proves that it can be done. With two strong sides of the coin the true value of European physics will be properly accounted for. ■

Ove Poulsen, EPS President

Highlights from European Journals

Editor's note

This new section in Europhysics News is launched to draw the attention of the readers to high quality original articles that have appeared recently in various physics research journals published in Europe. The choice is made by the Editors in Chief of these journals, with the help of their Editorial Board. As a start, only a limited number of European journals have been invited to participate: EPL (Europhysics Letters), NJP (New Journal of Physics) and all the sections of EPJ (European Physical Journal) and of J. Phys. (Journal of Physics). The highlight section will be open to others upon request, provided that their European character is fulfilled.

Presently, EPN checks the proposals with an open mind. A more selective process will be used when the number of submissions will move closer to the size limit allocated for the section. The idea is to give to the Editors in Chief the full responsibility for providing an image of their journals. They will have to balance between high level but seldom appearances and lower average level but more frequent ones. The wish of EPN, acting for EPS, is to attract an increasing number of authors – mostly European, considering the readership of EPN – towards these European journals. ■

The origami of life

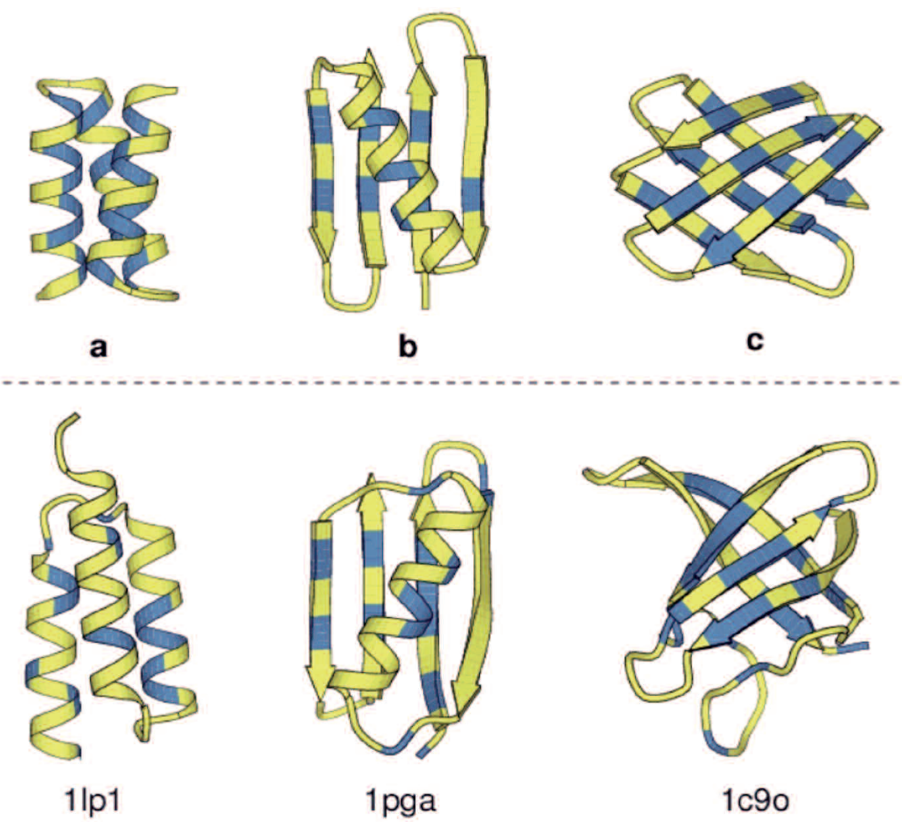
This paper ties together the biology of proteins with a novel phase of matter that protein structures are housed in. The key idea is that living matter is governed by physical law and understanding the underlying physics is vital for progress.

All living organisms rely upon networks of molecular interactions to carry out their vital processes. In order for a molecular system to display the properties of life, its constituent molecules must themselves be endowed with several features: stability, specificity, self-organization, functionality, sensitivity, robustness, diversity, and adaptability. The authors reflect upon how these molecular needs are met by known organisms, and they discuss properties of conventional phases of matter that make them poorly suited for supporting life. They postulate a novel molecular phase of matter and demonstrate that proteins, the functional molecules of terrestrial life, are perfectly suited to this phase. They explore, through an understanding of this phase of matter, the physical principles that govern the operation of living matter. The new ideas presented in this paper pertain to how advances in nanoscience and supramolecular chemistry can be harnessed for powerful applications and indeed for the ultimate development of physically-based artificial life itself.

This paper is a clear tutorial that is easily accessible to a broad audience and is specially suited to condensed matter physicists. ■

T.R. Lezon, J.R Banavar and A. Maritan, *J. Phys.: Condens. Matter* **18** (2006) 847–888

▼ **Fig. 1:** Ground state structures for designed heteropolymers of 48 units. In the model considered, each monomer is either hydrophobic (blue, dark) or polar (yellow, light), but there is otherwise no distinction between them. Varying the hydrophobicity pattern produces different ground state conformations shown in (a), (b) and (c). Each of these is a stable conformation for a marginally compact homopolymer, but the sequence of hydrophobic and polar monomers serves to select a single conformation as a well-defined ground state.

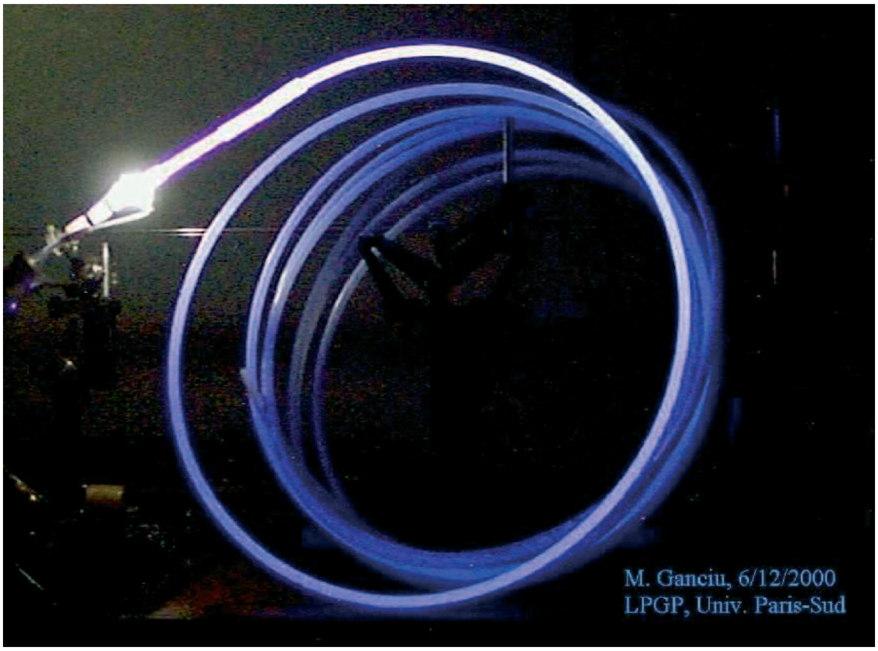


A high-resolution Ramsey-Bordé spectrometer for optical clocks based on cold Mg atoms

Optical clocks combined with the revolutionary technique of mode-locked femto lasers break new grounds for improved tests in fundamental physics and generation of ultrastable frequencies in the optical domain. Fermionic and bosonic magnesium is one of the few atomic species which offers handles for laser cooling and trapping as well as narrow clock transitions. This paper reports on the status and the prospects of a magnesium optical clock. In a Ramsey-Bordé interferometer resolutions as high as 290 Hz are obtained, which corresponds to a quality factor of $Q = 2.3 \times 10^{12}$. This is the highest quality factor ever obtained for atoms in free fall. An upper limit for the laser linewidth of 170 Hz is deduced from the atom interferometric signal. ■

J. Keupp, A. Douillet, T.E. Mehlstäubler, N. Rehbein, E.M. Rasel and W. Ertmer, *Eur. Phys. J. D* **36**, 289-294 (2005).

Transportation of nitrogen atoms in an atmospheric pressure post-discharge of pure nitrogen



Electric discharges have a long history. However, only recently, electric discharges operating in gases at atmospheric pressure have received increasing interest due to the easier use of such discharges for various applications.

Applications of electric discharges are based on the presence of charged and/or neutral excited species created in the discharge. Such atoms or molecules in excited states with high chemical energies often have long radiative lifetimes, so that they exist for seconds or even minutes when the electric excitation is no longer present. These excited species are observed either when a pulsed discharge is switched off or in a flow regime when the carrier gas has left the discharge region.

The present paper discusses the properties of a flowing post-discharge in pure nitrogen at atmospheric pressure, after excitation using a compact and low-power (15 W) plasma source. Spectroscopic measurements and numerical modelling of atomic nitrogen concentrations (initial values of around 10^{15} cm^{-3}) show transport of chemical energy over long distances (several metres) even when tubes of small diameters (a few mm) are used (see the figure showing fluorescence of a Manuril® tube, Φ = 6/8mm, 10 m length). The paper illustrates both the high efficiency of the low-power plasma source to dissociate nitrogen molecules and the fact that the dominating losses of atomic nitrogen in a flowing post-discharge are due to a slow volume recombination process.

Among the various possible applications of such a post-discharge - biological decontamination, surface deposition and chemistry, air treatment, and others …-, the efficient destruction of bacterial spores has already been demonstrated. For these applications, using nitrogen presents – besides its low cost – the important advantage of being non-toxic.

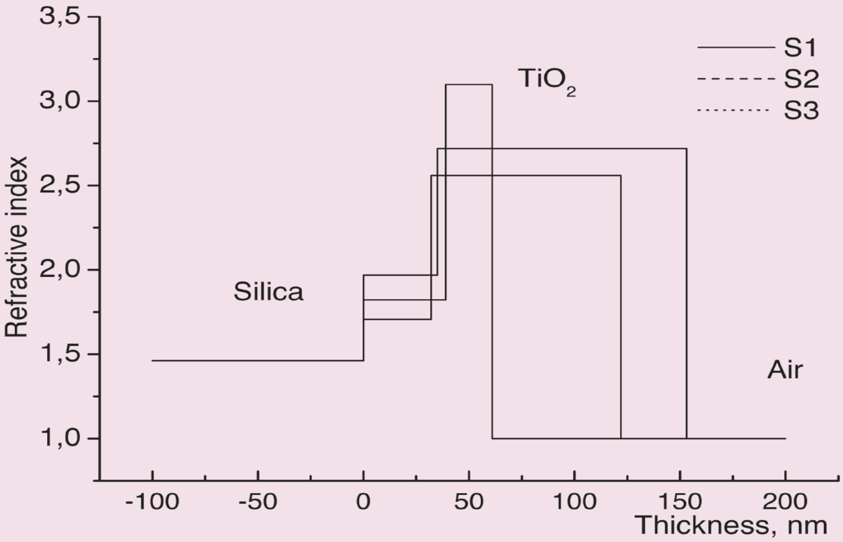
The approach used in this paper is also suitable for investigating surface recombination rates of nitrogen atoms for varying surface materials. ■

P. Fromy, A-M. Pointu, M. Ganciu and J. Orphal, *J. Phys. D: Appl. Phys.* **39**, 108–112 (2006).

Refractive index gradients in TiO_2 thin films grown by atomic layer deposition

Atomic layer deposition (ALD) is a thin film processing method that has extensively been studied because of its application potentials related to precise and convenient control of the film thickness, weak dependence of film thickness on the process parameters and possibility to obtain film with uniform thickness on large areas. The method is very promising for application in electronic technology but it has also great potential in processing optical coatings. Titanium dioxide (TiO_2) has frequently been used in high refractive index layers of multilayer optical coatings. These layers must usually have as high refractive index as possible and should, thus, contain high-density (crystalline) phases. Possible phase transitions that sometimes occur with increasing film thickness and may result in refractive index gradients could cause, however, additional problems in optical coatings. We investigated transversal inhomogeneity of crystalline TiO_2 films prepared by ALD and found that significant refractive index gradients can really exist in the films whereas in these cases the material with lower refractive index is formed in the initial stage of deposition on silica substrates (Fig.). Nevertheless, as our study also demonstrated, optimised ALD processes allow growth of crystalline TiO_2 films without those refractive index gradients. ■

A. Kasikov *et al*, *J. Phys. D* **39**, 54-60 (2006).



One possible structure for ALD coated TiO_2 layers.

2006 Agilent Technologies Europhysics Prize

The EPS and Agilent Technologies are proud to announce that the 2006 Agilent Technologies Europhysics Prize has been awarded to Professors Antoine Georges, Gabriel Kotliar, Walter Metzner and Dieter Vollhardt, for the Development and Application of the Dynamical Mean Field Theory. The Awards Ceremony was held during the 21st Condensed Matter Division Conference (CMD21), on Thursday 29 March 2006, in the premises of the Dresden University of Technology, in Dresden (D).

The Agilent Technologies Europhysics Prize, sponsored by the Agilent Technologies Foundation is one of the most prestigious physics prizes presented in Europe. Since 1975, the award has been given to leading scientists in nearly every internationally important area of condensed matter physics. The award is given in recognition of recent work by one or more individuals in the area of physics of condensed matter which represent scientific excellence.

Citation

Heavy-fermion compounds, high-temperature superconductors and many other materials with unusual properties, such as colossal magnetoresistance in manganites, led to a revival of studies of strongly correlated electron systems. Efforts to deal with correlation effects were already present in the 60's of the last century, in particular in studies of the Mott metal to insulator transition, experimentally observed in materials such as vanadium oxide. The full explanation of this phenomenon is one of the main achievements obtained with the Dynamical Mean Field (DMFT) method introduced by the winners of the 2006 Agilent prize.

The main theoretical paradigms previously available to describe metallic phases, such as electron energy band theory and Fermi-liquid theory, turned out to be inadequate for dealing with strongly correlated electron systems. Even if the insulating phase could be described in terms of electrons localized at atoms, strongly correlated systems are generically in the intermediate regime where the localizing electron-electron interaction is comparable to and competes with the delocalizing kinetic energy. These two terms are usually schematized via the Hubbard Hamiltonian with an on-site repulsion and with a hopping term between neighbouring sites. The competing effect leads to a variety of physical properties and to rich phase diagrams. The difficulty in dealing with these systems, even when they are schematized in terms of the simplest model Hamiltonian, is due to the intrinsic non-perturbative nature of the problem in the absence of the simplifying aspects of universality available, for instance, in classical critical phenomena. Solvable limits with a well-defined control parameter are therefore of invaluable help in understanding these systems.

Walter Metzner and Dieter Vollhardt introduced the method of dealing with correlated fermions on a lattice by a suitable rescaling of the hopping in the large dimensionality limit or more properly, in the limit of a large lattice coordination number, whose inverse is the control parameter. In this way they succeeded in maintaining the dynamical competition between the kinetic energy and the Coulomb interaction along with the discovery of the main simplification of the method, namely the locality of perturbation theory in this limit.

Antoine Georges and Gabriel Kotliar introduced a considerable technical and conceptual improvement in the construction of the DMFT that produced many applications to physical systems. By relating DMFT to the single impurity Anderson model, the full quantum many-body problem of correlated materials on a lattice or on the continuum was reduced to an impurity, self-consistently coupled to a bath of electrons. The single site problem retains the full dynamics of the original problem. In analogy with the classical mean field theory where a single degree of freedom (e.g. a spin on a site) is immersed in the self-consistent effective field (the Weiss field) of the remaining degrees of freedom, here a local set of quantum mechanical degrees of freedom on a single site are linked to the reservoir of the electrons via a frequency dependent function which plays the role of the self-consistent mean field and allows the electrons to be emitted and absorbed in the atom. A local description of correlated systems is achieved, which is amenable to calculations while the main features of competition between itinerancy and locality are still present.

Various extensions of the method are now considered e.g.: realistic one-particle and Coulomb interaction aspects are included by combining the local density approximation method and DMFT; short range space-correlations are introduced by switching from a single atom to a cluster.

The very successful applications of the method have covered numerous phenomena at the heart of the present research activity. To quote just a few of them besides the important success of Georges and Kotliar in explaining the metal-insulator transition, we can mention the doped Mott insulator, the competition of spin, charge and orbital order, the interplay between correlation and the electron-phonon interaction, the phonon spectrum of delta Plutonium and some general features related to quantum criticality.

In conclusion the DMFT represents one of the most powerful approaches to strongly correlated electron systems. In addition to the number of successes of the DMFT in model systems and realistic calculations, the applications of the method are still increasing and many extensions and developments are nowadays the object of the research of many groups worldwide. ■

▼ L. to R. Antoine Georges, Gabriel Kotliar, Dieter Vollhardt and Walter Metzner

Letters on the EPN 36/6 Special Issue

Editors note

In the 2005 Special Issue of EPN on "Nonextensive statistical mechanics: new trends, new perspective" (Vol. 36/6), the guests Editors amply developed their views on the subject through 15 features over an exceptional set of 48 pages. It seems that some readers from the same community see the field in different ways. EPN is too limited in space to open a forum of discussion in its pages. The subject will be closed for EPN after publication of the following two letters and a comment with its specific answer. ■

Letter to the Editors:

Roger Balian (SPhT • Saclay • France) and Michael Nauenberg (Physics Dept., University of California • Santa Cruz)

The 2005 special issue of Europhysics News (Vol. 36/6), entitled " Non-extensive statistical mechanics: new trends, new perspectives", contains a number of papers which make either misleading or incorrect claims. For the past decade one of the guest editors of this issue, C. Tsallis, and his collaborators and followers have generated a vast literature on this subject, organized conferences, and published several books. All of this promotion gives the wrong impression that the topic of your special issue is well established in statistical physics.

For systems in thermal equilibrium, which are characterized by a temperature T, the applications of the so called q-entropy extension of Boltzmann-Gibbs statistics are flawed, because the maximization of the q-entropy violates a fundamental law of thermodynamics for $q \neq 1$: then, temperatures that must be equal for systems in thermal contact cannot even be defined [1]. This flaw has recently been recognized by Tsallis, who has admitted that " the $q \neq 1$ theory ... by no means applies to thermal equilibrium" [2]. Unfortunately, this disclaimer is nowhere mentioned in your special issue. Instead, in one of the articles entitled "Nuclear astrophysical plasmas: ion distribution functions and fusion rates" [3], the authors apply the $q \neq 1$ statistics at a fixed temperature T to discuss in a purely hypothetical way how this might give rise to anomalous fusion rates in the interior of stars — while incorrectly claiming that such "distributions different from the Maxwellian one can be obtained axiomatically from non-standard, but mathematically consistent versions of statistical mechanics that use q-entropies" [3]. Indeed, a large bulk of the papers on q-entropy have been addressed to systems in thermal equilibrium, but to date the conclusions of these papers have not been retracted. On the contrary, these papers continue to be included in a "regularly updated bibliography, http://tsallis.cat.cbpf.br/biblio.htm", as publicized by the reference (2) of the article on "Extensivity and entropy production" [4] in this issue.

Concerning the application of the non-extensive q-entropy formalism to non-equilibrium stationary systems with long range forces, to quasi-stationary states, and to chaotic maps, the value of q is selected only through disputable numerical fits, never through theoretical arguments. On the other hand, not a single paper in this special issue gives a hint about the existence of strong controversies and disagreements on the validity of these applications.

1/ For example, the authors of the article entitled "Non extensive thermodynamics and glassy behaviour" [5] try to explain why molecular dynamics simulations of the mean-field coupled rotator model exhibit long-lived quasi-stationary states which violate Boltzmann statistics. They claim that their results show that " Tsallis' generalized formalism is able to characterize the dynamical anomalies". But they fail to point out that other physicists have reached exactly the opposite conclusion [6].

2/ Likewise, the author of the article entitled "Critical attractors and q-statistics" [7] claims that "it has been recently corroborated that the dynamics at the critical attractors ... obey the features of the q-entropy". However, in a recent paper on the same subject [8], P. Grassberger shows that "recent claims for the non-stationary behaviour of the logistic map at the Feigenbaum point based on non-extensive thermodynamics are either wrong or can be easily deduced from well known properties of the Feigenbaum attractor", and concludes that " non-extensive thermodynamics is (at least at the onset of chaos) just a chimera".

3/ In a paper of this issue entitled "Atmospheric turbulence and superstatistics" [9], the authors show that the q-entropy statistics fails to fit both the data for atmospheric turbulence, Fig. 2, and the data for Taylor-Couette turbulence, Fig. 3. But this failure is hidden from the casual reader, because the dotted curves are inconspicuously labelled "Gamma" instead of "Tsallis" or "q-entropy" Furthermore, it is claimed that the "superstatistics approach gives a plausible physical explanation to the entropic index q"; in fact, the authors define an index q related to temperature fluctuations, but this index coincides with that of the q-entropy only for the so-called Gamma statistics which does not fit the data at all. Moreover, the lognormal statistics, which does fit the turbulence data, is not linked up to the topic of this special issue, which is non-extensive statistical mechanics.

At best, q-statistics can be viewed as a phenomenology without any physical justification which provides interpolations between exponential and power law dependences in attempts of fitting data.

In a Brazilian newspaper, A Folha de Sao Paulo, March 3, 2002, Joel Lebowitz was quoted as saying "that the promotional movement around it [Tsallis q-entropy] has been more harmful than useful for science". We believe that this is particularly true for the Latin American statistical mechanics community, where many researchers have been misled into working on this "chimera". It is unfortunate that this special issue of Europhysics News has lent itself to this " promotional movement". ■

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Comment to

"Nonextensive Thermodynamics and Glassy Behaviour in Hamiltonian Systems" by A. Rapisarda and A. Pluchino, Europhysics News 36/6, 202 (2005).

F. Bouchet (INLN • Nice • France), T. Dauxois (ENS • Lyon • France) and S. Ruffo (Florence University • Italy)

The dynamics of the Hamiltonian Mean-Field (HMF) model [1] shows many intriguing non-equilibrium behaviours. In particular, it has been reported several times that the system get stuck into quasi-stationary states (QSS), whose lifetime increases with system size. As correctly pointed out by C. Tsallis and co-workers (see e.g. Refs. [2]), the presence of such non-equilibrium states is tightly linked to the fact that the infinite time limit and the thermodynamic limit do not commute in systems with long-range interactions. However, contrary to what is claimed in Ref. [3], the non-extensive statistics approach does not convincingly "explain" any of these non-equilibrium behaviours.

Two main quantities have been tested up to now: velocity distribution functions and correlation functions. In Ref. [4], the authors fit single particle velocity distribution functions in QSS using q-exponentials. They obtain a value of the index q = 7. In Ref. [3], an analogous fit of correlation functions with q-exponentials gives values of q between 1.1 and 1.5.

The fact of being in a non-equilibrium state could in principle allow the use of an entropy other than Boltzmann-Gibbs. However, there is up to now not a single paper which justifies the use of non-extensive entropy for the HMF model. Hence, there is no compelling reason of using q-exponentials as a fitting function. Moreover, as recalled above, different values of q are reported in the literature for the same model and the same physical conditions.

A general alternative approach has been introduced to explain the presence of QSS in systems with long range interactions. This approach begins by performing first the thermodynamic limit and then looking at the time evolution. It leads to associate to the HMF model appropriate Vlasov and kinetic equations. This method is fully predictive and has been extensively exploited in Ref. [5] to obtain the Vlasov equation predictions for the HMF model. Velocity distribution functions of QSS have been analysed, reaching the conclusion that they cannot be fitted by q-exponentials. This conclusion has not been questioned so far in the literature.

Restricting to homogeneous QSS, this approach also allows to derive properties of the correlation functions, deducing them directly from the HMF model [6]. Such homogeneous states are of paramount importance, since they appear to be "attractive" for a large class of initial conditions. For instance, it can be shown that the plateau values of the magnetization M_0 shown in Fig. 1 of Ref. [3], all converge to $M_0 = 0$ when N increases, which is a distinctive sign of homogeneity.

The Vlasov equation approach is just in a beginning stage. However, the already existing results are encouraging and we believe that the difficulty of treating inhomogeneous QSS is of technical nature. This problem will be solved in the near future. Hence, the conclusion of Ref. [3]: "However the actual state of the art favours the application of non-extensive thermostatistics to explain most of the anomalies observed in the QSS regime" is highly questionable. As a final remark, we think that, as physicists, we should pay great attention to the difference between "fitting" and "explaining". ■

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Reply to the Comment

by T. Dauxois, F. Bouchet, S. Ruffo on the article by A. Rapisarda and A. Pluchino, Europhysics News, 36/6, 202 (2005)

Andrea Rapisarda and Alessandro Pluchino
(Dipartimento di Fisica e Astronomia and Infn Università di Catania • Italy)

In the comment by T.Dauxois et al. [1] the authors question our application of nonextensive statistical mechanics proposed by Tsallis [2] and discussed in [3] to explain the anomalous dynamics of the Hamiltonian Mean Field (HMF) model. More specifically they claim that the explanation of the metastability found in the out-of-equilibrium dynamics is only a fitting procedure and is also in contrast with a previous application done in ref. [4]. This criticism mostly relies on recent studies based on the Vlasov approach and discussed in refs. [5, 6], where the authors claim to explain the anomalous behaviour of the HMF model in terms of a standard formalism. In order to reply to this comment we want to stress a few numerical facts and conclude with some final considerations.

1/ In our numerical simulations we consider always a finite number of particles, which plays the role of a collision term absent in the Vlasov equation. This collision term is very important since it drives the systems towards the equilibrium.

2/ In our paper [3], we use a finite initial magnetization which leads to a violent thermal explosion. The quasistationary state which follows is microscopically nonhomogeneous, with a hierarchical cluster size distribution [7]. The Vlasov-like approach proposed in [5] has severe problems in dealing with these inhomogeneities. Up to now all the derivations presented in the literature start from a homogenous metastable state, where no violent relaxation occurs [8]. In this case, the decay of the velocity correlation function is very fast (almost exponential), in remarkable contrast to what observed for an intial finite magnetization, where a q-exponential (with q > 1) is found [3, 8].

3/ The predictions of Tsallis thermostatistics [2] are successfully compared with the numerical results, as shown in figs.3,4 of ref. [3]. In this case, it is not true that we perform simply a fit of numerical data. By means of Tsallis statistics and using q-exponentials to reproduce extremely well the anomalous diffusion behaviour, we can predict the correlation decay with great precision and vice-versa. At variance, the results of the approach proposed by Dauxois et al. [5] have not been tested with numerical simulations, so that no real prediction can reasonably be claimed.

4/ The results presented in [3] are not in contradiction with previous papers since they refer to velocity correlations decay and not to the marginal velocity probability density functions discussed in [4], where the entropic index extracted was only an effective one and indicated a strong departure from a Gaussian shape. On the other hand, the possible application of Tsallis statistics in long-range Hamiltonian systems is confirmed by several other studies [9].

In conclusion the HMF model is a paradigmatic example of a large class of long-range Hamiltonian systems which have important physical applications, ranging from self-gravitating systems to plasmas. The nonhomogeneous metastability observed for the HMF model goes undoubtedly beyond standard Boltzmann-Gibbs statistical mechanics and has a dynamical origin, therefore a new kind of kinetics should be used [10]. In general, adopting different perspectives is a useful procedure to shed light on a tricky problem. Tsallis statistics is a good candidate to explain and interpret the strange behaviour of long-range Hamiltonian systems, and this is not in contradiction with other possible formalisms, including that one of Dauxois et al. (analogously the Langevin and the Fokker-Planck phenomenological formulations are not in contradiction with Boltzmann-Gibbs statistical mechanics). We have also successfully applied techniques normally used for glassy systems [7], and interesting connections with Kuramoto model and the synchronization problem have been advanced [8]. In any case further work is needed to understand in detail this intriguing new field.

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Letter to the Editor:

"On fallacies concerning nonextensive thermodynamics and q-entropy"

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On the question in the special issue 36/6 (2005) of Europhysics News it should be noticed that claims about the formulation of a grand-generalization of non-extensive thermodynamics, based on a so-called q-entropy, have given rise to a flood of papers which are receiving critical scrutiny: Several distinguished researchers in the area have pointed out the misconceptions involved in such an approach.

In a recent publication Peter Grassberger stated [1] that during the last decade has appeared a vast literature on a "new non-extensive thermodynamics" (NNET), which uses a maximum entropy principle with the Shannon entropy replaced by the Havrda-Charvat [2] (Tsallis) entropy [3,4], an approach plagued by misconceptions about basic notions [1,5-9]. The basic serious error committed by the followers of such line of thought, consists in considering that they have developed a generalization of the traditional, well established, and physically sound, statistical thermodynamics (founded by Maxwell, Boltzmann and Gibbs), which would cover all physical systems in nature, particularly including those with complex behaviour which they wrongly consider to be outside the scope of the latter.

The fundamental misconception behind this consists into identifying Havrda-Charvat structural α-entropy [2] (later called Tsallis q-entropy) with the thermodynamic entropy of a physical system [6]. Michael Nauenberg has forcefully shown that it is in fact inconsistent with the laws of Thermodynamics: He points out that for a q-index different from 1 it has been claimed that it leads to a formalism that is consistent with the laws of Thermodynamics, but, however, it can be shown that the joint entropy for systems having different values of q is not defined in their formalism, and consequently fundamental thermodynamic concepts such as temperature and heat exchange cannot be considered for such systems. Moreover, for $q \neq 1$ the probability distribution for weakly interacting systems does not factor into the product of the probability distribution for the separate systems, leading to spurious correlation and other unphysical consequences [5].

Related to these aspects of the question, we recall that in Statistical Mechanics the probability distribution (statistical operator) usually derived from heuristic arguments, can also be derived from a variational method, which is related to Information Theory [10-13]. It consists into making extremal — a maximum —, subject to certain constraints, a functional (superoperator) of the probability distribution (statistical operator). Such quantity, first introduced in Shannon's Theory of Communication [14], can be referred-to as a *measure of information*. It has also been called statistical measure and entropy, with the understanding that it is *informational-entropy*, and once again we emphasize the essential point that the different possible informational-entropies are not to be interpreted as the thermodynamic entropy of the physical system. Richard T. Cox has noticed that the meaning of such entropies is not the same in all respects as that of anything which has a familiar name in common use, and it is therefore impossible to give a simple verbal description of it, which is, at the same time, an accurate definition [15]. Edwin T. Jaynes has also commented that it is an unfortunate terminology, and a major occupational disease in that there exists a persistent failure to distinguished between the informational-entropy, which is a property of any probability distribution, and the experimental entropy of thermodynamics, which is instead a property of the thermodynamic state: Many research papers are flawed fatally by the authors' failure to distinguish between these entirely different things, and in consequence providing nonsense results [16], as it is the case with NNET.

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Report on ICALEPCS'2005

Axel Daneels • CERN • Geneva

From 10 - 15 Oct 2005, the "*European Organization for Nuclear Research*" (CERN) and the "*Centre de Recherches en Physique des Plasmas*" (CRPP) of the "*École Polytechnique Fédérale de Lausanne*" (EPFL), hosted the Europhysics Conference ICALEPCS'2005, the 10th "*International Conference on Accelerator and Large Experimental Physics Control Systems*" at the "*Geneva International Conference Centre*" (CICG).

ICALEPCS is the prime conference in the field of controls of experimental physics facilities: particle accelerators and detectors, optical and radio telescopes, thermo-nuclear fusion, lasers, nuclear reactors, gravitational antennas, etc. The initiative to create this series of biennial conferences was taken at the end of 1985 and an initial group of six laboratories, CERN, GANIL (Caen), HMI (Berlin), KFA (Jülich), LANL (Los Alamos), and PSI (Villigen) were called in to create the interdivisional group on *Experimental Physics Control Systems* (EPCS) within the *European Physical Society* (EPS) (1986) with the purpose, amongst others, to patronise these conferences. In a next step, CERN offered to organise the first ICALEPCS in 1987 in Villars-sur-Ollon.

The ICALEPCS circulate around the globe, in Europe, America and Asia, and are co-organised by the *Experimental Physics Control Systems* (EPS-EPCS) under the auspices of the EPS, the *Institute of Electrical and Electronics Engineers* (IEEE) through its *Nuclear and Plasma Science Society* (NPSS), the *Association of Asia Pacific Physics Societies* (AAPPS), the *American Physical Society* (APS), the *International Federation of Automatic Control* (IFAC), the *International Federation for Information Processing* (IFIP) through its *Technical Committee on Computer Applications in Technology* (TC5).

ICALEPCS'2005

ICALEPCS'2005, chaired jointly by Bertrand Frammery (CERN) and Jonathan Lister (CRPP-EPFL), was particularly auspicious: it fell in the *World Year of Physics*, and was strongly supported by the Swiss Federal Government, the Republic and Canton of Geneva and the French Authorities of the Département de Haute Savoie. The attendance reached 442 delegates from 160 Organisations (laboratories, universities, industries) in 27 countries (Europe, America, Asia, Oceania-Australia).

Opening Session

Axel Daneels (CERN), Chairman of the International Scientific Advisory Committee, who steered the ICALEPCS since their inception, welcomed the delegates. After having introduced ICALEPCS'2005 and having acknowledged the generous support from the Swiss Federal Government, the Republic and Canton of Geneva and the Département de Haute Savoie in France, he invited Mr. Carlo Lamprecht, Minister of Economy and Councillor of the State of Geneva to express his welcome and his support to the conference. Next Jonathan Lister, welcomed in turn the participants. His speech was followed by a presentation on the challenges raised by the LHC project – both the accelerator and the detectors – by Jos Engelen, Chief Scientific Officer of CERN.

Scientific programme: Session overview

Besides the recurrent Status Report, this year's event focussed issues of current concern: Process Tuning, Automation and Synchronisation, Security and other Challenges, Development Approaches, Hardware and Software Technology Evolution, Operational Issues and Evolution.

Status Reports

Several major new and planned experimental physics facilities around the world were reviewed with an emphasis on controls. Particle accelerators covered the LHC, J-PARC [the High Intensity Proton Accelerator Project proposed jointly by the Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK)] and CERN's Low Energy Ion Ring (LEIR). Synchrotron light sources presented the Synchrotron Light source in Trieste, Soleil and the Spanish facility ALBA. The fusion community discussed the controls of the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory, of Angara-5 (TRINITI, Troitsk) and the data challenges of ITER. Telescopes described the controls of the Atacama Large Millimetre Array radio telescope in the Andes (ALMA, an international collaboration between Europe, Asia, and the Americas) and the Low Frequency Array (LOFAR). CERN presented the control systems of the LHC particle detectors: the CMS electromagnetic calorimeter and ALICE. There were also presentations on SPring-8's 8 GeV X-ray free electron laser and on VIRGO, the 3 km French-Italian gravity wave detection facility.

This session, acted as an introduction to the next sessions that delved into more specific topics.

Process Tuning, Automation and Synchronisation

Automation systems are crucial for a reliable, coherent, safe and flexible operation of complex facilities such as NIF, VIRGO, ATLAS and LHC detectors. The operation of tokamaks such as JET (Abingdon, UK) and KSTAR (Daejeon, Korea), rely on real time measurements and accurate synchronization systems. Low-level radio frequency

◀ Welcome at CICG of M. Carlo Lamprecht. From left to right: Bertrand Frammery - Conference Chairman, Axel Daneels - Chairman of the International Scientific Advisory Committee, Mr. Carlo Lamprecht - Minister of Economy and State Councelor of Geneva, the bailiff and Jo Lister - Conference co-Chairman control systems were presented for the superconducting RFQs of the new Piave injector at INFN-LNL (Legnaro, Italy) and for the CERN LINAC-3 cavities. Synchrotron light sources, e.g. Indus-2 storage ring of CAT, (Indore, India) and Bessy II (Berlin, Germany) rely on Orbit control and active feedback loops to position their optical components.

Security and Other Major Challenges

Interlock systems combined with alarm handling systems monitor facilities that operate in harsh environments (radiation, temperature …). Security of computing networks for controls is an issue of concern at e.g. SPring-8 and CERN. The design of control systems for security and dependability was discussed in the frame of the "Dependable Distributed Systems" (DeDiSys) research project with the European Union. Dependability covers availability, reliability, maintainability, safety and security.

Development Approaches

Experimental physics facilities become more sophisticated and thus more demanding in matters of controls. Full featured control systems are huge projects that conflicts with the reduction in resources that prevails in our community. Laboratories are thus driven into multiple team collaboration to jointly develop systems based on commercial hardware and software components. To assure a streamlined and standard approach when integrating these components into a coherent system and to ease debugging, testing, deployment and maintenance, frameworks are developed: e.g. the Joint Controls Project(JCOP) for the LHC detector controls; TANGO, for synchrotron radiation facilities developed jointly by ALBA (Barcelona), ELETTRA (Trieste), ESRF (Grenoble) and Soleil (Paris); the Common Software (ACS), for the ALMA distributed control.

Hardware Technology Evolution

Control system architectures evolve towards a higher granularity thanks to the availability of small size boards with an Ethernet port. This approach reduces the cost and improves the overall reliability. Concerning more specifically the computer busses and interfaces, PciExpress tends to become the only standard to connect devices with high bandwidth requirements with standard PCI, for less demanding applications. In the domain of Networking, 1Gb/s Ethernet is a consolidated standard, but a bandwidth up to 100Gb/s can already be found in projects such as the ALMA. Networks with a low bandwidth are used as fieldbusses. Programmable logic devices are the building blocks of digital controllers and replace complex boards based on DSPs. Their importance is growing as they allow the integration of standard functions with custom application logic.

Software Technology Evolution

Middleware frameworks such as NIF's large scale CORBA framework have matured, and the attention is shifting from mere deployment towards easier development. Application developers can be shielded from particular middleware products and testing and integration of components can be facilitated through software simulation.

Access to remote distributed resources is increasingly based on Web and Grid technologies. HyperDAQ, an application to provide access to distributed DAQ systems, employs web and peer-to-peer technology. The Virtual Instrument Grid Service (VIGS), a part of the GRIDCC project, will use Grid computing to control distributed instrumentation (SINCROTRONE Trieste). XML related technologies are ubiquitous. Java 2 Enterprise Edition (J2EE) evolves towards light-weight containers as was illustrated by the Spring framework, and the use of Spring for LHC slow controls.

The use of knowledge technologies to support decision making in complex control rooms of ESA was also reported.

Operational Issues session

Machine operations are tightly coupled to data management, alarm handling and remote collaboration. Operational information are managed through relational databases, as e.g. the configuration database for LHCb, while commercial Geographical Information Systems (GIS) are applied for accelerator configuration management. Intelligence is added to alarm handlers in order to reduce the incidence of unimportant alarms. Common frameworks, such as CERN's Directory Services, tend to be introduced to integrate diverse systems operationally.

Dealing with Evolution

Experimental physics facilities involve large investments and evolve during their lifetime. Control systems must thus cope with this evolution while protecting the investment, therefore their architectures must be modular, data driven and based on commercial products and standards. Examples are the JAPC Code (Java API for Parameter Control) developed to ease the programming of the LHC Application Software. Evolution often also implies proliferation of computers. Facing this phenomenon and in order to limit hardware failure and maintenance, Spring-8 applied the "virtualisation technology" by which many computers are accommodated into a reduced number of "virtual machines" each with its independent resources (CPU, discs, etc) as if they were stand-alone. Three virtualisation approaches were discussed: Emulation of hardware or specific guest operating systems; Multiplexing of physical resources by software; "Application shielding" to isolate application from each other. Contrary are medical accelerators which for safety and regulatory reasons are designed for minimal upgrades and limited improvement in their life.

Round-Table

About 80 people took part in a round-table discussion on the in-kind procurement of large systems for collaborative experiments. The future ITER project was taken as example, although the ILC (International Linear Collider, the next facility after LHC) will have similar considerations. The discussion aroused much interest but generated little conflict. The general agreement was that ITER should be bold and be as restrictive as possible on standards and equipment, even though there was no evidence suggesting this has been possible in the past.

Closing Session

ICALEPCS'2005 closed upon an invited talk on the test system for the Airbus 380 (Airbus Industries) and with an invitation to ICALEPCS'2007 in Knoxville (Tennessee, USA), jointly hosted by Dave Gurd (SNS, Oak Ridge National Laboratory, Oak Ridge, USA) and Karen White (Thomas Jefferson National Accelerator Facility, Newport News, USA). Bertrand Frammery (CERN) wrapped up the event, and Daniele Bulfone (Sincrotrone Trieste), Chairman of the ICALEPCS Selection Committee, awarded "Best Posters" prizes to Jijiu Zhao (IHEP-Beijing), Thomas Birke (BESSY), Marco Lonza (ELETTRA) and Michel Jonker (CERN).

Industrial programme

The scientific programme was complemented by a three days exhibition involving 17 companies and 10 particularly well attended technical seminars by which companies presented their views on the evolution of their technology as well as their strategy.

Pre-conference workshops and tutorial

In the week preceding ICALEPCS'2005, 150 controls specialists attended four workshops: ***EPICS (Experimental Physics and Industrial Control System)*** organised by Matthias Clausen (DESY, Hamburg), ***ACS (ALMA Common Software)*** organised by Gianluca

Chiozzi (ESO, Munich), ***TANGO***, organised by Andy Götz (ESRF, Grenoble) and a ***Joint ECLIPSE Workshop*** organised jointly by Matthias Clausen and Andy Götz. These workshops were held in France at Archamps, the Haute-Savoie's business park near Geneva and fully supported by the *Conseil Général de la Haute-Savoie*.

Markus Völter (Völter-Ingenieurbüro für Softwaretechnologie, Germany) gave a tutorial on ***"Model-driven Development of Distributed Systems"*** at the "*Geneva International Conference Centre*" (CICG).

Social Programme and Technical Visits

The social programme featured: a welcome reception sponsored by Hewlett-Packard; wine tasting parties, sponsored by the cantonal wine producers; an organ and brass concert in the St Pierre Cathedral in Geneva's old town, sponsored by the Republic and Canton of Geneva; a cruise with a banquet on lake Geneva, and at the closing session, the ICALEPCS tenth anniversary cake offered by the Local Organising Committee.

Technical visits, attended by more than 120 participants, were organised to two of CERN's LHC experiments (CMS and LHCb), and to the CRPP-EPFL Tokamak.

Sponsors and Partners

ICALEPCS'2005 was sponsored by the *Swiss Federal Government*, through the CICG, the *Republic and State of Geneva*, the *Département de la Haute Savoie* (France) and its *Archamps site* as well as by several industrial companies: *Agilent Technologies*, *Hewlett-Packard* and *Siemens*. *DELL*, ICALEPCS' 2005 partner, supplied the entire informatics infrastructure. *SWISS*, the Swiss airline, ICLEPCS'2005 official carrier, offered a free return flight to an Indian delegate.

Participants from Industrially Emerging Nations

The registration fee of 26 participants from Industrially Emerging Nations was waived and 17 of them received in addition a grant through one of the following organisations: the EPS, namely the "*East West Fund*" and the "*Young Physicists Fund*" (YPF); the "*Abdus Salam International Centre for Theoretical Physics*" (ICTP) in Trieste; the programme "*SCOPES - Scientific Co-operation between Eastern Europe and Switzerland 2005-2008*" of the *Swiss National Science Foundation* (SNSF) and the *Swiss Agency for Development and Cooperation* (SDC) and INTAS, the *International Association for the Promotion of Co-operation with Scientists from the New Independent States of the Former Soviet Union*;

ICALEPCS'2007

ICALEPCS'2007 will be held in Knoxville (Tennessee, USA), jointly hosted by Dave Gurd (SNS, Oak Ridge National Laboratory, Oak Ridge, USA) and Karen White (Thomas Jefferson National Accelerator Facility, Newport News, USA). ■

Acknowledgement

ICALEPCS'2005 gives thanks for its success to the overwhelming support from the international EPS-EPCS community and the dedication of many colleagues with a very special thanks to those who contributed behind the scene and benevolently: Guy Baribaud, retired from CERN, was instrumental in obtaining financial support for the participation of scientists from industrially emerging nations. Linus Jirden designed all the ICALEPCS'2005 graphics.

More on ICALEPCS

For more details on ICALEPCS in general, cf. www.icalepcs.org; on ICALEPCS'2005, http://icalepcs2005.web.cern.ch/Icalepcs2005

Discovery Space

A feasibility study of the business case for the on-line use of a science thematic park for educational purposes

The aim of the Discovery Space (D-Space) project is the development of a virtual science park connecting schools, universities, science museums etc. with a network of robotic telescopes around the world. Students, teachers, researchers and interested individuals will have the opportunity to use these telescopes in real time. (Fig.)

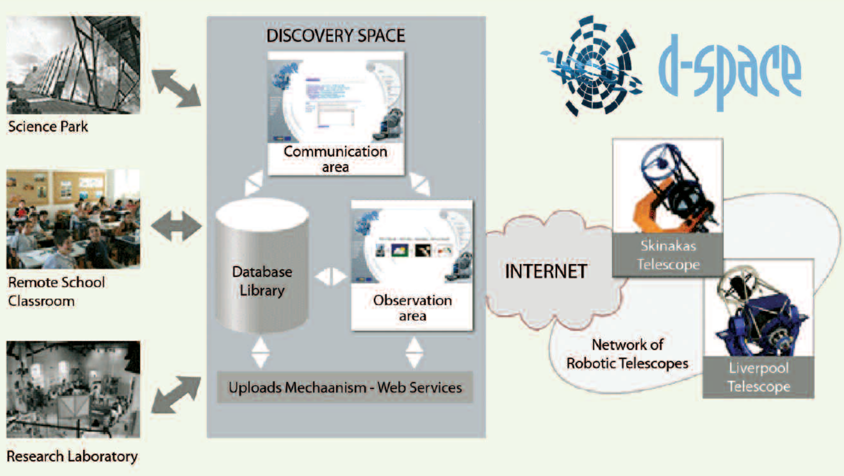
The D-Space partners, comprising representatives from science, education, communications technology, and business development, will first study whether the use of robotic telescopes for educational purposes is economically and technically feasible, and scientifically useful. Many of the partners have been involved in similar projects on a smaller scale, such as the EUDOXOS and the Schools Observatory projects.

If we are successful in proving our case, D-Space will then provide innovative educational services which will make space observations using robotic telescopes possible not only for research centres, but also for schools, science museums and individuals. This will provide science and physics education possibilities that go beyond traditional models.

For more information, please visit the project's website www.discoveryspace.net, or contact M. Sotiriou, sotiriou@qplan.gr.

The members of the Consortium are: Q-Plan (GR), Ellinogermaniki Agogi High School (GR), Telefonica I+D (ES), OTE (GR), Science Projects (UK), Telescope Technologies LTD (UK), FORTH (GR), European Physical Society (FR), MENON Network (BE)

The DISCOVERY SPACE project is co-financed by the European Commission within the framework of eTEN Programme eLearning Action



▲ The D- Space Service

EPS sponsors physics students to participate in the reunion of Nobel Laureates at Lindau

Martin C.E Huber, EPS past-Président

During the last week of June, each summer, Nobel laureates in the disciplines of natural sciences gather in the picturesque island-city of Lindau on Lake Constance. Count Bernadotte initiated these reunions of Nobel laureates in 1951 to help German science to return to international standards in the time following the Second World War. Nowadays, these meetings bring laureates together with selected students from the entire World — from 54 nations, last year. The 2005 reunion was one of the hitherto infrequent gatherings, where laureates of physics, chemistry and medicine/physiology came together for a multi-disciplinary meeting.

Through the good offices of Mr. Simon Newman, one of the first Editors of Europhysics News, the European Physical Society was offered the opportunity to nominate and sponsor two students to attend the 2005 reunion. In a gesture towards their host in Mulhouse, yet strictly respecting the new set of selection criteria for young scientists that had recently been established by the "Council for Lindau Nobel Laureate Meetings", EPS selected two advanced physics students from the Université de Haute Alsace.

The meetings of Nobel laureates in Lindau offer great opportunities for students: not only will they hear brilliant, authoritative talks on a wide variety of scientific, science-policy and societal topics — they can also meet and discuss with the laureates. The reunion of last June started on Sunday afternoon with the opening of the meeting by Countess Sonja Bernadotte and by Petra Meier to Bernd-Seidl, the Mayor of Lindau, followed by a number of welcoming addresses by ministers and other dignitaries. The scientific programme began on Monday with lectures by individual laureates. The topics of the forty lectures offered to the audience ranged from physics themes, such as 'The Neutrinos' by Masatoshi Koshiba, 'Einstein's Nobel Prize and Modern Nanoelectronics' by Klaus von Klitzing or 'The Development of Particle Physics' by Martinus Veltman, to subjects connecting physics with biology, such as 'A Biosensor using Living Cells' by Ivar Giaever, 'Real-time Magnetic Resonance Imaging: Echo-planar Imaging' by Sir Peter Mansfield or 'Singularities in the Origin and Evolution of Life' by Christian de Duve. Other talks related chemistry — and science in general — with the environment and society, namely 'Atmospheric Chemistry and Climate in the Anthropocene' by Paul Crutzen, 'Science, Society and Sustainability' by Sir Harold Kroto, and 'Public Understanding of Science' by Robert Richardson.

▲ Riccardo Giacconi lecturing on 'Interaction Between Basic and Applied Research'

The high points of the 2005 meeting were undoubtedly the panel discussions with participation of laureates from all the disciplines represented in Lindau. The discussions covered the topics 'Evolution of Matter, Universe and Life' on Monday, 'Biology in the Post-Genomic Era' on Tuesday and 'Energy Shortfall and Global Warming' on Wednesday. A lively exchange between students and laureates took place during the formal session. And many students could be seen in face-to-face discussions with laureates during the coffee breaks that regularly followed the panel discussions. Indeed, the Nobel laureates remained accessible to the students throughout the meeting. Occasions for informal contact with laureates also arose at the social get-together of all participants on Monday evening, where the young researchers were invited for a buffet dinner and dance with laureates and student colleagues, and during the boat trip and visit to the island of Mainau, which closed the reunion on Friday in a relaxed atmosphere.

This summer, the meeting in Lindau will be devoted to chemistry and that of 2007 will most likely bring together laureates of medicine and physiology. Thus the next meeting of physics laureates is expected to take place in 2008. It is hoped that EPS by then will be able to sponsor a sizeable contingent of young researchers. ■

◀ François Vonau and Régis Stephan from the Université de Haute Alsace in Mulhouse during a break in the Lindau Congress Hall together with EPS Past-President Martin Huber and the person who had arranged the participation of EPS-sponsored students, Simon Newman — one of the first Editors of Europhysics News.

EPS-AG[1] and EPAC[2]

[1] European Physical Society Accelerator Group, [2] European Particle Accelerator Conference

I rather fancy it was due to Maurice Jacob's[1] renowned powers of persuasion that the Organizing Committee of Europe's first Particle Accelerator Conference, EPAC'88, decided on the creation of an EPS Interdivisional Group on Accelerators. It happened over an informal dinner in the CERN cafeteria, one damp and dreary winter evening in January 1988.

Today's Accelerator Group (AG)[2] is composed of physicists and engineers whose aim is to promote research and development of accelerators, storage rings and similar devices as well as their applications. Membership remains relatively modest in spite of campaigns to attract new members, perhaps due to the fact that activities lean more towards applications than towards pure physics.

An Elected Board, composed of 18 members with a biennial, one-third turnover to ensure continuity, is responsible for the organization of EPAC[3], which regularly attracts around 900 delegates in even years at different venues around Europe[4].

The tenth conference in the series, EPAC'06[5], will take place in June in Edinburgh. Sixty-five oral presentations are scheduled, and in total over 1000 posters will be displayed at the end of each afternoon during the lively sessions, totally de-coupled from the oral presentations to promote communication and exchange.

Since 1994, a session has been devoted to the presentation of the EPS-AG European Accelerator Prizes. They are awarded for a recent, significant, original contribution to the accelerator field from a scientist in the early part of his or her career, and for outstanding achievement in the accelerator field. A third prize will be awarded for the first time this year to a young scientist showing particular promise for the future on the basis of work submitted to the conference.

Another regular feature is a dynamic industrial exhibition, with an associated oral session on technology transfer and industrial contacts. A fifth edition of a small booklet on future accelerator projects and upgrades is in preparation to inform exhibitors of new business prospects. These initiatives underline the importance of maintaining strong ties between laboratories and industry in the accelerator field.

Thanks to European laboratories and industry more than 60 young scientists from all over the world will be sponsored to attend EPAC'06, including several of the best Joint Universities Accelerator School (JUAS)[6] students. Close ties are also maintained with the CERN Accelerator School (CAS)[7].

Continuity, coordination and communication characterize AG and EPAC organization. Participation at EPAC has grown steadily, with 40% of the participants and contributions coming from non-European countries.

Integrating accelerator conference activities at the international level is achieved through a Reciprocity Agreement with EPAC's two sister conferences, the US and Asian PACs, whereby the Organizing and Programme Committee Chairs of each series participate actively in the organization of sister conferences. The OC Chairs also meet informally each year during a PAC Coordination Committee (PACCC), convened by the EPAC Conferences Coordinator.

An unexpected spin-off of regional accelerator conference collaboration was the creation of the Joint Accelerator Conferences Website[8] (JACoW). In the mid-nineties, Ilan Ben-Zvi of the Brookhaven National Laboratory proposed the creation of a single website for the publication of the proceedings of the regional accelerator conferences. This subsequently developed into a flourishing international collaboration in electronic publication, now extending to the CYCLOTRONS, DIPAC, FEL, ICALEPCS, ICAP, ICFA Advanced Beam Dynamics Workshops, LINAC and RuPAC conference series.

Forty-seven sets of proceedings have been published since 1996, including scanned PAC and EPAC proceedings dating back to the outset of both series in the pre-electronic era. The LINAC conference series is actively pursuing its own scanning project, and a proposal to extend the scope of JACoW to include scanned versions of "extinct" conferences or journals is currently under discussion.

Since electronic publication of proceedings does not happen by waving a magic wand, considerable effort has been invested in editor education, whereby "apprentice" editors attend yearly JACoW Team Meetings to learn about electronic publication techniques. Valuable "hands-on" experience is also organized during each PAC and EPAC, where all contributions are processed on-line by an international team of increasingly "seasoned" editors. This considerably speeds up publication (all EPAC'04 contributions were available only 9 days after the conference, and the proceedings were published in final form two months later) in a consistent format thanks to common templates and tools.

A further spin-off of JACoW's yearly Team Meetings has been the development of a Scientific Programme Management System (SPMS), an Oracle-based application under General Public License[9], GPL. Originally developed to manage activities related to scientific programmes, from abstract submission through to proceedings production, the SPMS now offers the functionality to manage delegate and industrial exhibition registration, as well as refereeing.

Clearly all of this would not have been possible without the unfailing support of the PAC and EPAC Organizing Committees, both moral and financial.

Furthermore, during the Awards Ceremony at EPAC'04, they formally acknowledged the achievements of the

[1] Former President of the EPS
[2] http://epac.web.cern.ch/EPAC/EPS-AG/Welcome.html
[3] http://epac.web.cern.ch/EPAC/
[4] EPAC conferences have taken place in Rome, Nice, Berlin, London, Sitges, Stockholm, Vienna, Paris and Lucerne
[5] Edinburgh, Scotland from 26 to 30 June www.epac06.org
[6] http://juas.in2p3.fr
[7] http://cas.web.cern.ch/cas
[8] www.jacow.org
[9] www-esh.fnal.gov/SPMS
[10] http://accelconf.web.cern.ch/accelconf/jacow/JACoW_citation.htm

JACoW Collaboration to disseminate scientific knowledge throughout the accelerator community[10].

So EPAC now has a rich history and many anecdotes still make us laugh: victim of its own success, the *controlled chaos* of EPAC'88 in Rome when the expected number of delegates exploded from 400 to 750; the planned balmy outdoor gala dinner on a Mediterranean beach in Nice in 1990… under a tropical downpour; a speaker who disappeared abruptly from off the back of the stage in Vienna in 2000 ….

To conclude, EPAC has evolved into an established, respected forum for the state of the art in accelerator technology.

However, the world is growing smaller and change is in the air with a move to merge the three regional accelerator conferences into one I(nternational) PAC, with one major accelerator conference per year. A number of hurdles and objections need to be addressed, but the idea is taking root. Should it come to pass, one may be in no doubt that the EPS-AG will welcome the international accelerator physics community to share in Europe's rich cultural and scientific heritage. ■

Christine Petit-Jean-Genaz, CERN

Report: EPEC 1[1]

[1] the 1st European Physics Education Conference

EPEC-1 was the first European Physics Education Conference organized by the Physics Education Division of the European Physical Society. The Physics Education Division is a forum for physics education issues and takes part in forming the physics education policy of the European Physical Society. The aim of this new conference series is to strengthen physics education, both at school and at University, and to enhance contacts between physics teachers at different levels and between teachers and researchers in physics education in Europe.

The venue for the conference (July 4-7, 2005) was the Physikzentrum in Bad Honnef, (Germany) not far from Bonn. The Physikzentrum occupies a large 19th Century mansion and is now owned by the University of Bonn, which sublets part of it to the DPG, the Berlin-based German Physical Society. It is used as the venue for a wide range of meetings and conferences.

The Scientific programme

The scientific programme consisted of four main elements: a series of plenary lectures devoted to topics in physics education, a second series of plenary lectures dealing with subjects at the frontiers of physics, afternoon sessions composed of 20 minute talks based on contributed papers, and a poster session. The physics education lectures covered schools and universities, and included a contribution on Advancing Physics and curriculum change by Jon Ogborn (Institute of Education) as well as a discussion of problem based learning and the environment of physics education by Derek Raine (Leicester). Other plenary contributions to the Physics Education strand included: Dieter Schumacher (Dusseldorf) on the use of e-learning tools in student labs; Jacques Treiner (Paris) on the teaching of physics in relation to other disciplines; Elena Sassi (Naples) on the methods, aims and achievements of physics education research in schools; Hendrik Ferdinande (Ghent) on the status of the Bologna process for the harmonization of European higher education, following the 2005 Bergen declaration; and a joint presentation by two Dutch school teachers, Jef Colle and Frits Hidden, concerning the award winning HiSPARC project in which high school students, their teachers and research scientists cooperated in the creation of an extensive array of detectors for the study of the highest energy cosmic rays.

The inclusion of the 'Frontiers' lectures was a widely welcomed feature of the programme, and it was gratifying to observe the willingness of some of Europe's leading researchers to participate in a conference that was primarily directed towards education. The speakers in this part of the conference included Werner Hoffman (Max Planck Institute for Nuclear Physics, Heidelberg) who spoke on elementary particles and the cosmos, Uwe Czarnetski (Bochum) who described recent advances in Bose-Einstein condensates and the construction of matter lasers; and Klaus Ensslin (ETH, Zurich) who discussed the work that he and his group have carried out in nanophysics and the fabrication of nano-scale devices. A somewhat less conventional contribution to the 'Frontiers' theme was provided by Guy deMortier (LARN, Namur) who described some of his many applications of nuclear techniques to problems in medical physics and archaeology. Particularly fascinating was his account of the physical evidence that the 'stones' of the great pyramid in Egypt were cast in situ, rather than being cut and raised as is conventionally believed. All of the Frontiers speakers were asked to present their talks in a way that might provide useful material (as well as interest and insight) for the school and university teachers in the audience. This objective was substantially achieved, and all concerned seemed to benefit from the interaction.

The contributed talks and posters presented work from 20 countries. The most heavily represented countries were Germany (the host nation), the UK and the Netherlands, but there were multiple contributions from several others, including three from the USA. Topics were divided fairly equally between school and university level physics education, though the majority of the presenters were university-based. Several of the talks concerned the use of computers, either as a multimedia platform or in the context of lab work. Another theme that emerged with surprising strength was the teaching of quantum physics. On the more theoretical front were contributions on anchored media in the context of situated learning and a cognitive model for teaching undergraduate physics. The mixture was rich and varied, but as usual it served mainly to show the immense amount of work that remained to be done in almost all areas of physics education research and curriculum development.

EPEC-2

As the first in a projected series of EPEC conferences, the organizers were keen to gather the views of the participants on issues such as the venue, timing and content of EPEC-2 which is planned for 2007. Two points emerged with particular strength from a lively session on this topic. First, the need for more time to be devoted to discussion rather than presentation. Second, the fact that there is no ideal time to hold such a meeting if school teachers are to attend. However, it did seem that early September might be better than early July for the majority. National physical societies generously provided financial support for a number of teachers to attend EPEC-1, however, so severe are the pressures on teachers that, in some places at least, teachers were unable to make use of this largesse despite its availability. ■

Erik Johansson and Robert Lambourne

Fermionic atoms in an optical lattice: a new synthetic material

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The demonstration of Bose-Einstein condensation, ten years ago, has initiated a wave of research on quantum degenerate gases [1,2]. Close to absolute zero temperature the atoms almost come to a standstill and a window on the quantum nature of many-particle systems opens up. It has now become possible to establish a link between quantum gases and the physics of electrons in a solid. Ultracold fermionic atoms have been trapped in a crystal structure formed by interfering laser beams [3,4]. The properties of this synthetic material can be changed at will. Switching between conducting and insulating states has been demonstrated, and by tuning the interactions between the atoms, an intriguing regime beyond basic solid state models has become accessible. Even the dimensionality of the system is controlled. One-dimensional Fermi gases have been created and weakly bound molecules, existing only in one dimension, have been observed [5]. The unique versatility of atoms in these optical lattices makes researchers optimistic to study a whole range of phenomena linked to solid-state physics. Text-book style experiments, answers to open questions and new effects will probably be seen. For example, it has been proposed that the physics underlying high-temperature superconductivity may be mimicked in these systems [6,7]. In the following we give a general introduction to this novel research field, describe first experimental results on fermions in optical lattices and provide an outlook to this vibrant field.

Creating ultracold gases

The route towards zero temperature in a gas of atoms is a narrow path which circumvents solidification by keeping the atomic cloud at very low densities. To go along this track the experiments exploit the mechanical effect of laser light to slow down atoms, followed by evaporative cooling of the atoms in a magnetic trap. Upon reaching temperatures of 100 Nanokelvin and below, the experimental efforts are rewarded with a quantum many-body system of ultimate controllability and access to microscopic understanding. The achievement of Bose-Einstein condensation in a weakly interacting gas of atoms has given a first taste of the new possibilities [1,2]. It could be witnessed how the gas condensed into a single quantum state displaying the behaviour of one quantum mechanical wave function. The investigation of weakly interacting Bose-Einstein condensates were soon accompanied by successful efforts to create quantum degenerate Fermi gases [8], which exhibit a fundamentally different behaviour due to Pauli's exclusion principle.

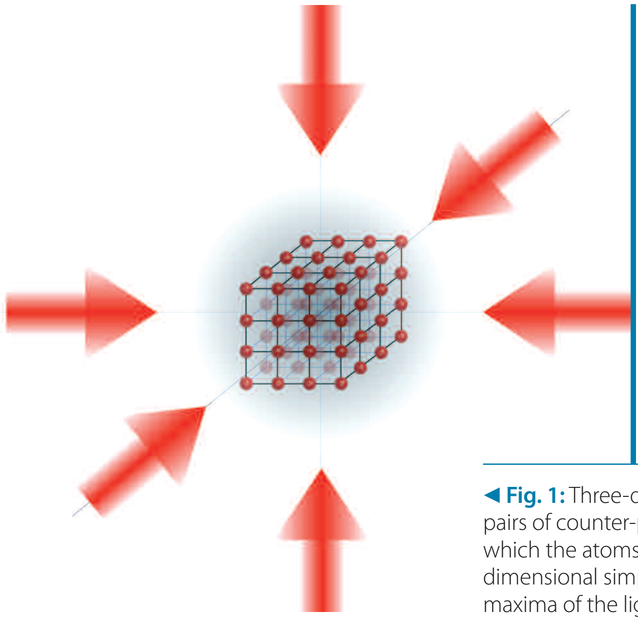
Optical Lattices

An intriguing tool to manipulate ultracold quantum gases is the optical lattice. It is created by up to three mutually perpendicular standing laser waves. Therein the atoms experience a periodic potential due to the interaction of the induced electric dipole moment of the atoms with the laser light [9]. For frequencies of the lattice laser which are below the atomic resonance frequency the atoms are attracted towards regions of high laser intensity. Therefore an anti-node of the standing wave acts as a lattice site. Three standing waves produce a cubic lattice structure with a separation of typically 400-500 nm between adjacent lattice sites, see figure 1. In addition, the Gaussian beam profile gives rise to a force pointing towards the beam centre, where the atoms are harmonically confined. The periodicity of the optical lattice results in a band structure for the trapped atoms, which is a particularly suitable picture if atom-atom collisions can be neglected. As we will see below, the physics of an interacting quantum gas in the optical lattice can often be described by the Hubbard model, which plays a key role in the description of many intriguing phenomena in modern condensed matter physics.

Imaging Fermi-surfaces

In the experiment [4] we sympathetically cool a gas of fermionic ^{40}K atoms with bosonic ^{87}Rb atoms, the latter being subjected to forced evaporation. After reaching quantum degeneracy for both species we remove all rubidium atoms from the trap. For the potassium atoms we reach a final temperature of $T/T_F = 0.25$ (T_F: Fermi temperature) with up to $2{\cdot}10^5$ particles before loading them into a three-dimensional optical lattice.

Assuming zero temperature, we expect that all states up to the Fermi energy E_F are occupied in the optical lattice. For a homogeneous periodic potential the lowest band would be only partially filled if the Fermi energy is lower than the width of this band. The underlying harmonic trapping potential, present in the experiment, leads to a quadratic increase of the potential energy with the distance from the trap centre. Hence, for a given Fermi energy the filling of the lattice is maximal in the centre of the trap and decreases



◀ **Fig. 1:** Three-dimensional optical lattice. An ultracold gas of atoms is trapped by three pairs of counter-propagating laser beams. Each pair produces a standing laser wave in which the atoms experience a periodic potential. All three pairs generate a three-dimensional simple cubic lattice structure, where the atoms are trapped in the intensity maxima of the light.

towards the edges of the trap [10]. A band insulator starts to form in the centre of the trap when the Fermi energy reaches the width of the lowest band. A further increase of the Fermi energy, which corresponds to a larger number of atoms in the trap, enlarges the size of the insulating region until the Fermi energy matches the energy of the second band which is then filled similarly.

In order to gain experimental insight into the filling of the optical lattice we apply a method which allows us to directly observe the Fermi surfaces. The intensity of the optical lattice is slowly ramped down as to avoid non-adiabatic transitions of the atoms from one band to another band. As illustrated in Fig. 2 this maps the quasi-momentum distribution of the atoms inside the lattice onto the real momentum distribution of the expanding cloud [11]. This distribution is then measured by absorption imaging of the cloud after ballistic expansion. The shape of the distribution corresponds to the projection of the Fermi surface for different fillings, as shown in Fig. 3.

By changing the intensity of the optical lattice beams we could reversibly vary between a conducting state and a band insulating state. Initially a conducting state is prepared by loading the atoms into an optical lattice with comparatively low beam intensities, so that the overall harmonic confinement is comparatively weak and the bandwidth larger than the Fermi energy. By increasing the laser power the atoms are pushed towards the trap centre where a band insulator starts to form. Our studies show that this process is reversible if carried out slow enough to allow the atoms sufficient time to tunnel to neighbouring sites [4].

Fermionic atoms interacting in an optical lattice: The Hubbard model and beyond

Due to the low temperatures in the experiment the energy between colliding atoms is so low that collisions are dominated by partial waves with zero angular momentum, i.e. s-waves. Consequently, a spin-polarized Fermi gas is effectively non-interacting, since Pauli's principle does not allow s-wave collisions, which are of even parity. However, the situation is different if the Fermi gas is prepared in an equal mixture of two different spin states, between which s-wave collisions are permitted. The s-wave collisions are characterised by a scattering length *a*, which is positive for repulsive and negative for attractive interactions. In the experiment the potassium gas is prepared in two different magnetic sublevels of the hyperfine ground state, which represent the two spin states.

The physics of interacting atoms in the optical lattice can be accessed by an important simplification. It is possible to prepare all atoms in the lowest band and regard the atoms as hopping from one lattice site to the next, as illustrated in Fig. 4. This motion is characterized by the tunnelling matrix element *J* between adjacent sites. If two atoms happen to be on the same site the atom-atom collisions give rise to a short range interaction *U*, which is proportional to the scattering length *a*. This was pointed out by D. Jaksch and coworkers who suggested that neutral atoms in an optical lattice are well described by a Hubbard Hamiltonian [12]. The proposed ideas led to the experimental observation of a transitions from a superfluid to a Mott-insulating phase for bosons, using a Bose-Einstein condensate loaded into a three dimensional optical lattice [13,14].

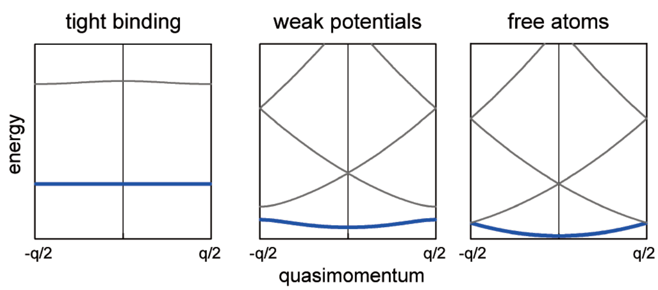
For fermionic atoms the Hubbard Hamiltonian in an optical lattice reads:

$$H = -J \sum_{\{i,j\},\sigma} \hat{c}^{\dagger}_{i,\sigma}\hat{c}_{j,\sigma} + \sum_{i} \varepsilon_i \hat{n}_i + U\sum_{i} \hat{n}_{i,\uparrow}\hat{n}_{i,\downarrow}$$

The first term contains the kinetic energy and is proportional to the tunnelling matrix element *J*. The operators $\hat{c}^{\dagger}_{i,\sigma}$ and $\hat{c}_{j,\sigma}$ are the fermionic creation and annihilation operators for a particle in the spin state σ (up or down) at lattice sites *i* and *j*. The occupation number of the site *i* is given by $\hat{n}_{i,\sigma}$. The second term takes account of the additional harmonic confinement of the optical lattice. The last term describes the interaction energy in the system and is determined by the on-site interaction *U*.

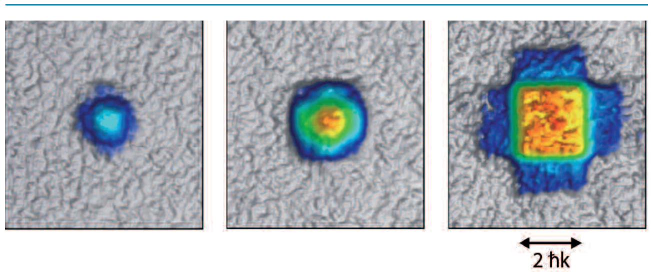
It is the control of parameters which makes the atomic realisation of Hubbard models unique. The intensity of the laser standing waves controls the barrier between the lattice sites, i.e. the tunnel coupling *J*. This allows tuning of the kinetic energy and of the time scale for transport. It also gives direct access to the dimensionality of the system. For example, a one-dimensional situation is created by suppressing tunnelling in two directions, using two standing waves with very high intensities. Further, the on-site interaction *U* can be tuned to negative or positive values. Even the statistics of the particles on the lattice can be changed by forming bosonic diatomic molecules from two fermionic atoms of different spin.

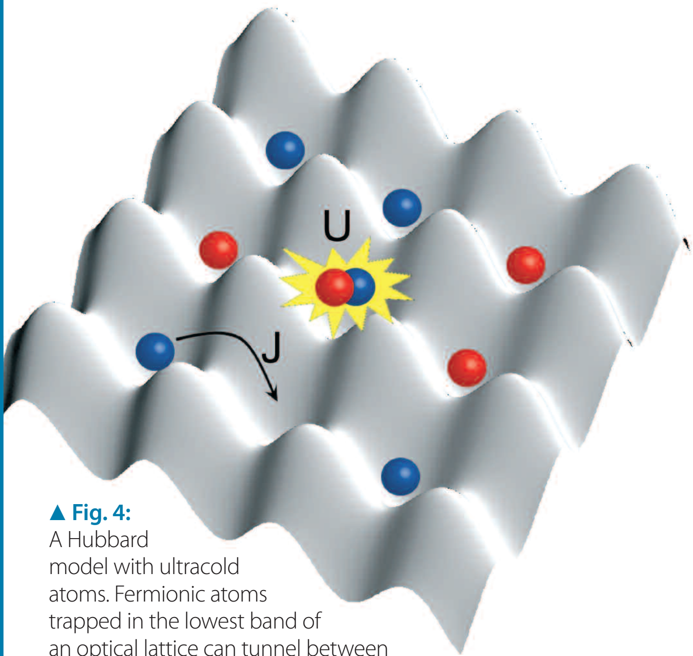
In the experiment we make use of a Feshbach resonance to tune the collisional interaction between two atoms, i.e. the *U* in



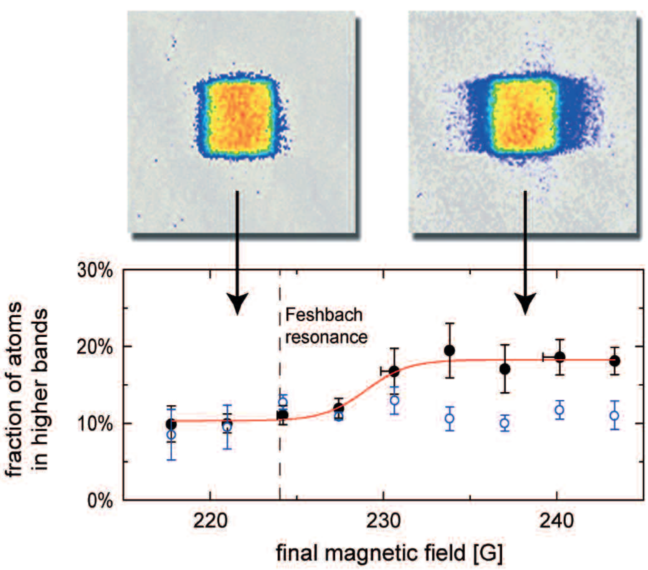
▲ **Fig.2:** Measuring the quasimomentum distribution. If the lattice potential is adiabatically lowered the quasimomentum distribution is mapped onto real momentum, since quasi-momentum is conserved. As the laser intensity is reduced, the lowest energy band transforms from being practically flat, in the tight binding limit, to a parabolic dispersion relation of free particles. Adiabaticity requires the process being slow enough as to avoid transitions between different bands. For example, the quasimomentum distribution of a completely filled lowest band is mapped onto a momentum distribution with momenta between $-\hbar q/2$ and $+\hbar q/2$, where *q* is the spatial frequency of the lattice potential.

▼ **Fig. 3:** Observing the Fermi surface. The absorption images are taken after adiabatically lowering the lattice potential followed by 9 ms of ballistic expansion. The false colour distributions are projections on the imaging plane and represent the quasimomentum of the atoms in the optical lattice. The boundary of the distribution reveals the Fermi surface. The atomic density increases from left to right. At low densities the Fermi surface is of spherical shape and the corresponding projection is seen. With increasing atomic density and atom number in the trap the Fermi surface develops a more complex structure showing extensions towards the boundary of the first Brillouin zone, as seen in the middle. In the frame on the right hand side the filling of the lattice in the trap centre exceeds unity such that higher bands are populated which show up beyond the square shape of the first Brillouin zone.





▲ Fig. 4: A Hubbard model with ultracold atoms. Fermionic atoms trapped in the lowest band of an optical lattice can tunnel between lattice sites with a tunnelling rate *J*. Due to Pauli's principle, tunnelling is only possible if the final lattice site is empty or occupied with an atom with a different spin. Two atoms with opposite spin localized at the same lattice site have an interaction energy *U*, which can be likewise positive (repulsive interaction) or negative (attractive interaction). The interplay between *J* and *U* and the filling determines the physics of the system.



▲ Fig. 5: Interaction induced coupling between Bloch bands. If the interaction energy U between particles on the same lattice site becomes comparable to the band gap, the single band Hubbard model breaks down. The strong interaction leads to a coupling between different bands. The two false color images show the measured quasimomentum distribution before (left) and after (right) strong interaction between the atoms. The interaction has been induced by sweeping the magnetic field across a Feshbach resonance. Quasimomentum states outside the first Brillouin zone become occupied which demonstrates the interaction induced coupling between the bands. The transfer of population occurs in one direction only, since a lower value for the intensity of the lattice beam has been chosen for this direction. (The figure is reprinted with permission from M. Köhl, H. Moritz, T. Stöferle, K. Günter, T. Esslinger, Phys. Rev. Lett. 94, 080403 (2005). Copyright 2005 by the American Physical Society.)

the Hubbard model. In a Feshbach resonance an applied magnetic field induces a coupling between different collisional channels which leads to a resonant behaviour of the scattering length a as a function of the magnetic field. Starting from a background value a_{bg} the scattering length increases with increasing magnetic field and diverges to plus infinity at the resonance position, then it switches to minus infinity before smoothly approaching the background value again. The typical width of such a resonance is a few Gauss.

To investigate the atom-atom interactions in the optical lattice we prepare the Fermi gas in two different spin components and produce a band insulator in the lowest band for each component, i.e. per lattice site there is one particle in each spin state. Starting from a weakly interacting situation we ramp the magnetic field over the resonance of the scattering length. After crossing the resonance we measured the population in each band and observed an increased population in the higher bands, see Fig. 5. Due to the large increase of the interaction we actually entered a regime beyond the standard Hubbard model. For a full description of the experiment higher bands would have to be taken into account since the on-site interaction exceeds the band gap. These models are notoriously difficult and a simpler approach to get a rough understanding of the experimental observations is to consider the low-tunneling limit, where we can describe each lattice site as a harmonic oscillator with two interacting particles. This model can be solved analytically [15] and shows that crossing the Feshbach resonance for the scattering length transfers part of the population to higher harmonic oscillator states, which corresponds to the observed population of higher bands. Although this approach does not give satisfying quantitative agreement with our observations, it gives qualitative insight.

Fermi gases in one spatial dimension: Confinement induced molecules

Quantum gases in one spatial dimension are a unique quantum model system due to the dominant role of quantum fluctuations. Many characteristics are not encountered in two or three dimensions, and, one-dimensional systems provide an ideal testing ground for quantum many-body physics due to the existence of exactly solvable models. The experimental research on one-dimensional atomic Fermi gases is only just beginning and we want to briefly discuss the first results.

An optical lattice produced from two standing laser waves generates a potential resembling an array of tubes, as shown in the upper part of Fig. 6. In each tube the particles can move only along the tube axis whilst the motion in the radial direction is frozen out. We used this lattice configuration to realize a quantum degenerate one-dimensional atomic Fermi gas. With the fermionic potassium atoms in two different spin states this can be considered to be a Luttinger liquid with tunable interactions. In a first experiment we studied the atom-atom interactions in the presence of a Feshbach resonance and were able to observe a new form of weakly bound molecules which exist only when the motion of the particles is restricted to one spatial dimension. Our experimental findings confirm the theoretical prediction for a one-dimensional atom gas that there always exists a bound state, irrespective of the sign of the scattering lengths. This contrasts with the usual three-dimensional situation, in which a stable molecular bound state is found only for positive values of the scattering length. In the one-dimensional case, the zero-point energy, due to the confinement in the radial direction, turns out to be enough to stabilize a bound molecular state. In the experiment we used radio-frequency spectroscopy to measure the dissociation energy of the molecular states and were thereby able to quantitatively verify the theoretical prediction, see Fig. 6.

Outlook

The physics of fermionic atoms in optical lattices covers a wide range of concepts in modern condensed matter physics and beyond. Experiments which now appear to be within reach are the creation of a Mott-insulating or an anti-ferromagnetic phase, where the repulsive interaction between atoms in different spins should cause a pattern with alternating spin up and spin down. For attractive interactions, it should be possible to study the superfluid properties in the BEC-BCS crossover regime inside an optical lattice. In general, fermionic atoms in optical lattices are much closer to real materials and provide a richer physics than their bosonic counterparts, but they are also more difficult to understand. A particular tantalizing prospect is, that fermionic atoms in optical lattices may provide solutions to unanswered question in condensed matter physics, such as high-temperature superconductivity. The challenge here is twofold. One central requirement is to reach extremely low temperatures inside the optical lattice. The second challenge is how to extract the information on the quantum many-body state from the experiment. To test new approaches and techniques with optical lattices one-dimensional systems will play a crucial role since they allow a comparison between exactly solvable models and the experimental findings. The experiments can then easily be extended to two or three dimensions. In the future, optical lattices of different geometric structure, superlattices or lattices with disorder, will most likely be implemented in experiments. New directions include very strong interactions, mixtures of bosons and fermions and polar molecules. Besides simulating quantum systems, optical lattices are a promising system for the development of a quantum computer. The optical lattice can be regarded as a quantum register with each atom on a lattice site acting as a quantum bit. Whilst the initial preparation of such a quantum register with thousands of qubit seems manageable, it is the controlled interaction between different atoms and the readout of single bits which represents the challenge. ■

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More information about the research group can be found at www.quantumoptics.ethz.ch

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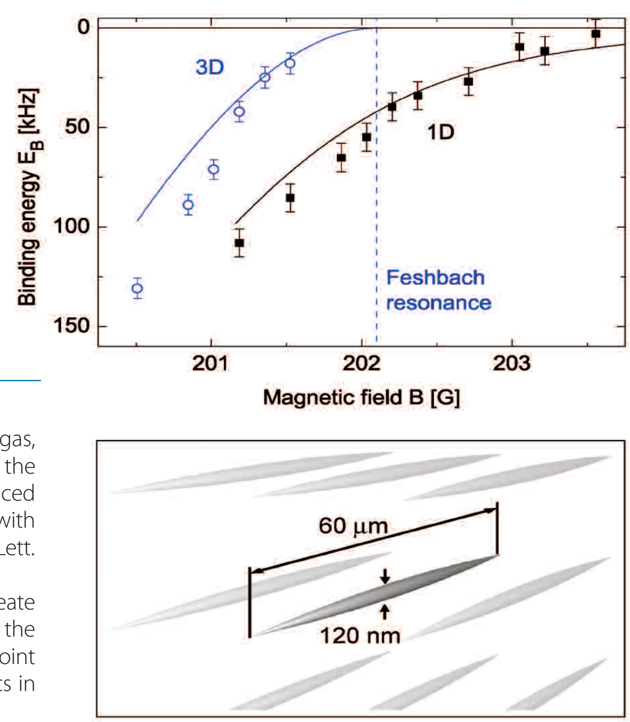

▶ **Fig. 6:** A one-dimensional atomic Fermi gas.
Top: Measured binding energy of a pair of atoms. In a three-dimensional gas, bound states exist only on the left side of the Feshbach resonance, where the scattering length is positive. In contrast, in one dimension confinement-induced molecules exist for any value of the scattering length. (The figure is reprinted with permission from H. Moritz, T. Stöferle, K. Günter, M. Köhl, T. Esslinger, Phys. Rev. Lett. 94, 210401 (2005). Copyright 2005 by the American Physical Society.)
Bottom: An optical lattice made from two standing laser waves is used to create an array of one-dimensional quantum gases. Radially the gas occupies only the vibrational ground state of the potential and the motion is restricted to zero-point oscillations. In the axial direction the gas is weakly confined and the physics in this dimension is studied.

The origin of the Earth's magnetic field: fundamental or environmental research?

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The origin of the Earth's magnetic field is a long-standing issue, which has captured the attention of many renowned scientists. If William Gilbert, André-Marie Ampère, René Descartes, Edmond Halley, Karl-Friedrich Gauss, Lord Blackett, and many others who contributed to the development of science, have worked on this problem, it is mainly because it was related to a very practical issue of critical importance: navigation at sea. This is not so true anymore, now that satellites provide the precise latitude and longitude without the need for us to rely on the Earth's internal magnetism. Yet the question of the origin of the Earth's magnetic field is so natural that it is still the object of very competitive research. Nobody can ignore that the compass needle points toward the north, and it is a bit irritating that we still cannot offer a complete physical understanding of why it is so. The problem has therefore become an active field of fundamental research in which significant progress has been made in the last few years using combined theoretical, experimental and numerical approaches. By its very nature, the problem is interdisciplinary and lies at the interface of physics, geophysics and applied mathematics. This problem has recently received considerable attention in the press because of the concern of a possible reversal of polarity of the Earth's magnetic field in the near future. Considering that we risk seeing our planet unshielded from the solar wind, understanding the field generation mechanism again appears to be a societal concern and a legitimate goal of environmental research.

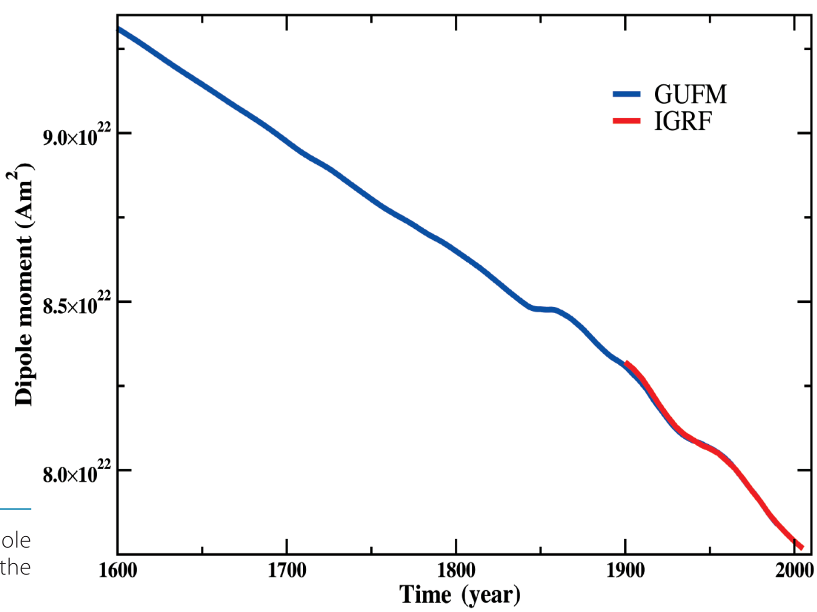
I will summarise here the basics of our present understanding of the generation of the Earth's magnetic field and then ponder on the scientific clues supporting the possibility of an approaching or imminent polarity reversal.

The origin of the Earth's magnetic field

When the Earth formed some 4.5 billion years ago, heavy elements concentrated at the centre, as a result 3000 km below our feet lies the largest of our planet's oceans: the core of liquid iron (mixed with traces of lighter elements), a sphere of 3400 km in radius. As the pressure increases towards the heart of the Earth, the iron solidifies and we find a solid inner-core, which occupies a volume of 1200 km in radius. It is in this metallic core that the magnetic field of the Earth originates. Temperatures at such a depth are above 3000°K and thus well above the Curie point (at which metals lose their ferromagnetic properties). A magnetic field can therefore only be sustained if electrical currents circulate in this ocean of liquid iron. However, Ohmic dissipation would suppress any unsustained electrical current in the Earth's core within some 20 kyr, yet there has been a magnetic field on Earth for millions of years. This is attested by the study of the ancient field recorded in sediments and lavas (known as paleomagnetic records). This means that there must be a process that regenerates electrical currents in the Earth's core against Ohmic dissipation.

The study of paleomagnetic records of the Earth's magnetic field also revealed a most puzzling feature: the Earth's magnetic field has reversed its polarity several times during its history in an apparently chaotic manner. The self-excited dynamo mechanism was first proposed by Sir Joseph Larmor in 1919 to account for the magnetic field of sunspots. This theory, called the *dynamo theory* for short, proposes that the non-magnetic solution ($\boldsymbol{B} = \boldsymbol{0}$) in a magnetohydrodynamic flow can become unstable if the flow is vigorous enough. This sort of instability can easily be introduced using a simple mechanical disk device (see the box), it is not as straightforward when it concerns a uniform volume of conducting fluid. A major cause of concern was first identified by Thomas Cowling, as early as 1934. Cowling found that an axially symmetric field cannot be maintained by dynamo action. This result suppresses the hope for any simple axially symmetric description of the dynamo process (a tempting approach considering the strong symmetry of the Earth field). In fact an even more general result came afterwards, and is known as Zeldovich's theorem: no two-dimensional solution can be sought. The problem has to be envisaged directly in three-dimensions of space, without the hope of a first simplified spatial approach.

The problem was formalised just after World War II by Walter Elsasser. Despite the early bad news of Cowling's theorem, it is the only theory that can account for the observational constraints. Besides, a remarkably nice feature of the resulting equations is their invariance under a change of sign of $\boldsymbol{B}$. If a velocity field of space and time $\boldsymbol{u}(\boldsymbol{x},t)$, a temperature field $T(\boldsymbol{x},t)$, and a magnetic



▶ **Fig. 1:** The strong decrease of the magnetic dipole moment over the last four centuries as revealed by the GUFM and the IGRF field models.

field $\boldsymbol{B}(\boldsymbol{x},t)$, can be identified that satisfy the governing equations; then the same velocity and temperature fields together with the opposite magnetic field $-\boldsymbol{B}(\boldsymbol{x},t)$ also satisfy the equations. This property (resulting from a linear equation governing the evolution of $\boldsymbol{B}$ and a Lorentz force quadratic in $\boldsymbol{B}$ in the momentum equation) does remarkably well in accounting for reversals. The two polarities do not need to correspond to two different hydrodynamic states and reversals can be thought of as transitions from one magnetic solution to another.

Another critical issue concerns the properties of liquid iron. Like all liquid metals, liquid iron dissipates electrical currents much more efficiently than heat and momentum. In other words, the ratios of the kinematic viscosity or thermal diffusivity to the magnetic diffusivity (these ratios are known respectively as the *magnetic Prandtl number* and the *Roberts number*) are exceedingly small (of the order of 10^{-6}). Since dynamo action requires motions to be vigorous enough to counteract magnetic diffusion, it means that they are extremely vigorous in comparison, say, to viscous effects. The ratio of these two effects is known as the *Reynolds number*. A large Reynolds number means a strong connection with the difficult problem of hydrodynamic turbulence. In the case of Earth core dynamics, this issue is made even more challenging by the rapid rotation of our planet. The Coriolis force, as well as the magnetic Lorentz force, strongly affects the turbulent flow, reducing turbulence, but also making it very anisotropic. The properties of this rapidly rotating magnetohydrodynamic turbulence are, as yet, far from understood.

Significant progress has been achieved over the last few years. Numerical models succeeded in solving the proper set of equations in the relevant geometry. Yet models are restricted so far to a very remote parameter regime, dominated by viscous forces. Efforts are underway to try to push models to the right force balance. Experimental fluid dynamos were also created simultaneously in 1999 in Riga (Latvia) and Karlsruhe (Germany), but the flows in these first experiments were extremely confined (guided by well established analytical dynamo flows). The first objective of the new generation of experiments is to reduce the constraints on the flow and thus gain insight into the dynamo solution.

Why is the Earth field dominated by an axial dipole? How does it reverse? What is the role of turbulence in the dynamo process? How does the system dissipate the energy at small scales? These are some of the open questions that researchers are trying to address.

The self-excited dynamo: a magnetic instability

Dynamo action (the conversion from kinetic to magnetic energy) works so efficiently in a bicycle dynamo that it is not straightforward at first to capture what makes the subject so difficult and interesting! The first critical issue is that an everyday dynamo relies on a permanent magnet. Usually the magnet rotates within a loop and the varying flux will induce an alternating electrical current in the coil. This principle can be slightly modified to produce a continuous current, a process known as the *Faraday Disk Dynamo* (introduced by Faraday in 1831). If a conducting disk revolves while being permeated by an applied magnetic field (as depicted in fig. a), a potential difference will be induced between the axis and the rim of the disk, thus driving an electrical current if these are connected by a wire. The magnetic flux through the disk and the electromotive force (obtained by integrating $\boldsymbol{u} \times \boldsymbol{B}$ across the disk of radius r, assuming a uniform normal field B) are

$$\Phi = B\pi r^2 \qquad \text{and} \qquad \mathcal{E} = \frac{\Omega B r^2}{2} = \frac{\Phi\Omega}{2\pi}$$

This setup is however not a *self-excited dynamo*, since it relies on a permanent magnet. If one now replaces this magnet with a solenoid of inductance L (as in fig. b), one now faces an instability problem. If the rotation rate is small enough, the resistivity will damp any initial magnetic perturbation. If the rotation rate is sufficient, then the system undergoes a *bifurcation* and an initial perturbation of the field will be exponentially amplified by *self-excited dynamo action*. Introducing M, the mutual inductance between the solenoid and the disk, we can use

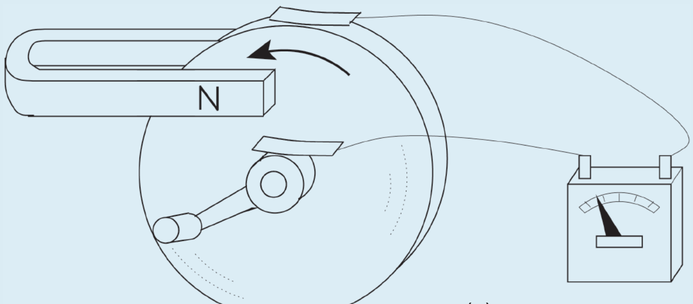
$$\Phi = MI \qquad \text{to rewrite} \qquad \mathcal{E} = \frac{M\Omega I}{2\pi}$$

Then, R being the electrical resistivity of the complete circuit, electrical currents are given by

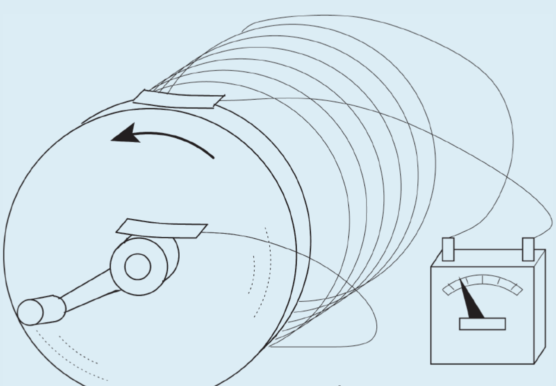
$$L\frac{dI}{dt} + RI = \frac{M\Omega I}{2\pi}$$

It follows that the system becomes unstable and an electrical current grows in the circuit provided

$$\Omega > \Omega_c = \frac{2\pi R}{M}$$



(a)



(b)

The approaching polarity reversal

While this field of research has made significant progress over the last few years, it has also received considerable attention in the press because of the concern of an approaching polarity reversal. Indeed, it has even been proposed that we are currently at the very beginning of such a geomagnetic reversal. Since these concerns are guided by observational facts, we will briefly review them here.

The dipole moment decay

The usual way to measure the strength and orientation of the dipolar component of the geomagnetic field is to use the dipole moment. It is defined using the first terms of the spherical harmonic expansion. It is a convenient notion, because it can also be recovered in the past using paleomagnetic records (neglecting the averaged effect of higher moment).

Rather than using brute magnetic observatory data, we rely here on smoothed models based on these measurements. These are the geomagnetic field model GUFM (Jackson *et al.*, 2000) over 1600-1990 or the International Geomagnetic Reference Field –IGRF (Mandea and MacMillan, 2000) going back to 1900. These models differ only slightly and we will use both to highlight the robust features. Both of these clearly reveal (see Figure 1) the rapid and relatively steady decrease of the geomagnetic dipole moment over the last four centuries. This constitutes the original and primary motive for pondering the possibility of an approaching reversal.

As striking as it may be, this decrease is not necessarily meaningful, especially if the present magnitude of the dipole moment is not small compared to that of the past. Indeed paleomagnetism reveals that the geomagnetic field amplitude is a fluctuating quantity and the present decrease could just be part of such fluctuations. In fact it turns out that, the present dipole moment is still significantly higher than its averaged value both over the last polarity interval (800 Ka) and the three preceding ones (0.8-1.2 Ma), see Table 1 (Valet *et al.*, 2005).

Another interesting property of the Earth's dipole moment is its direction, especially its tilt angle, the tangent of which reveals the relative strength of the axial dipole component (i.e. aligned with the axis of rotation) to the equatorial one. This angle is represented versus time in Figure 2. It is noticeable that the angle is presently rapidly increasing toward 90°. In other words, the dipolar component is becoming increasingly axial. This is just the opposite of what is expected for a reversal, simply reflecting the fact that the equatorial dipole is, at the moment, decreasing even more rapidly than the axial dipole.

The magnetic dip pole acceleration

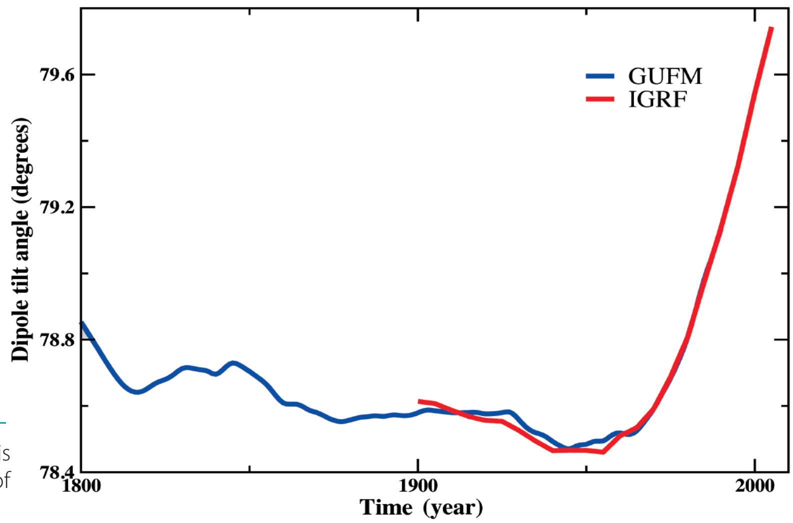
Besides the global spherical harmonic expansion of the field, one can also think about locally defined quantities: the magnetic dip poles. These are the two places on Earth at which a magnetic needle would stand straight up. It is important to capture the distinction between these points and the dipole moment orientation discussed above. While the poles of the large scale dipole field identified in the previous paragraphs, using a spherical harmonic expansion, are naturally antipodal one to the other, the magnetic dip poles are local objects affected by all components in a spectral expansion. As a result, they can move independently of one another.

It turns out that the position of the northern magnetic dip pole is often measured during scientific expeditions, and it was recently found out that its velocity is rapidly increasing, reaching the huge value of 40 km/year over the last few years, whereas its peak-velocity had been of some 15 km/year over the last century. This sudden increase in the northern magnetic dip pole velocity is thought to be a harbinger of a sudden change in the behaviour of the field, which is possibly entering a phase of reversal. This has been the cause of considerable excitement. However, the first striking surprise is that, in the other hemisphere, the southern magnetic pole velocity has kept decreasing over the last few years and is well below 10 km/year! Besides, just as for the global dipole, the north magnetic dip pole is cruising toward the geographic pole and not away from it!

In fact the magnetic dip pole can be understood as the zero of the horizontal component of the field. Plotting isovalues of the horizontal field strength (see Figure 3) it can be shown that the north magnetic dip pole is simply an ill defined quantity, and a minute change in the field can yield a huge shift in the zero position (i.e. in the dip pole position), whereas the south magnetic dip pole is a well constrained quantity (Mioara and Dormy, 2003).

Magnetic flux patches

Another possible sign of an approaching reversal is the evolution of the magnetic field structure at the boundary between the core (where dynamo action takes place) and the mantle (largely insulating). Thanks to the insulating nature of the mantle (the first 300 km below our feet), spherical harmonic models can be continued downward to this depth. The field there is much more complicated than at the surface of the Earth, as the downward continuation reveals finer scale structures. Among these structures, while the globally dipolar nature of the field is still clearly present and the magnetic flux globally reverses its sign at the equator, some patches of reversed flux are present in both hemispheres. It happens that while there were 2 such patches in the northern hemisphere in 1980, this number has increased to 6 in 2000 (meanwhile a merger of two patches has brought their number down from 4 to 3, including a larger one, in the southern hemisphere). Of course, if these patches became so large and numerous that they began to cover the core surface, the polarity would be reversed! In fact it turns out that this is the way some of the numerical dynamo models reversals occur. At the moment, these patches extend over some 15% of the Earth core surface. Besides, we shall, of course, note that this increase in the number of reversed patches is the



▶ **Fig. 2:** Inclination of the geomagnetic dipole. The field is presently becoming increasingly aligned with the axis of rotation (at 90°).

direct signature in the physical space of the decrease of the dipole moment reported before in the spectral domain.

The overdue reversal

Finally one last element could point toward the possibility of an approaching reversal: the last reversal dates back some 800.000 years ago, while seven reversals have occurred during the last 2 million years, so that… we could be overdue! The reversal rate of the Earth's magnetic field is however far from constant. The long-term average (over hundreds of Myr) is of 1 reversal per million years (the maximum value, when averaged over a few million years, is of some 6 reversals per million years). Some polarity intervals, known as superchrons, even lasted for tens of millions of years! This argument is therefore not very convincing.

Perspectives

A striking property of dynamo action seems to be its ability to work on a large variety of natural bodies. Most planets in the solar system (Venus and Mars excepted) exhibit a magnetic field, but the dynamo instability also occurs on even larger scales. The Sun (100 times the Earth in radius) exhibits a magnetic field, which reverses with a relatively regular period of 22 years. On an even larger kiloparsec ($3x10^{19}$ m) length-scale: galaxies exhibit their own large-scale magnetic field, and there again the only well accepted explanation is self-excited dynamo action. To highlight this amazing range of scales, we should just stress that in the units relevant to the galaxy, the Earth would be a nano-object! Yet a similar process is at work in all these objects (of course, under different parameter regimes).

Date/Period	Dipole moment	Source
In 2005	7.776×10^{22} A m^2	IGRF
In 2000	7.779×10^{22} A m^2	IGRF
Over the last 800 Ka	$7.5\pm1.7 \times 10^{22}$ A m^2	Valet *et al*, 2005
Over 0.8-1.2 Ma	$5.3\pm1.5 \times 10^{22}$ A m^2	Valet *et al*, 2005

▲ **Table 1:** Dipole moment as provided by the International Geomagnetic Reference Field in 2005 and 2000 and the averaged value during the last 800 kyr and the 0.8-1.2 Ma interval. The present dipole moment is significantly stronger than the average over both periods.

In conclusion, while dynamo action and the origin of the magnetic fields of planets, stars, and galaxies constitutes an exciting scientific challenge; evidence for an imminent reversal remains rather weak. Moreover, the typical timescale for a reversal is expected to be of the order of 1000 years, so that it should not constitute a major source of urgent social concern. Does that mean that such research, exciting as it may be, should not be supported? Clearly it should. Researchers trying to understand the origin of the geomagnetic field do so for the sake of physical understanding, and for the improvement of our general knowledge; not because they fear an imminent reversal. More and more programmes (both national and international) are emerging to strengthen applied research, directly aimed at environmental concerns. It might be tempting for some fields of research to put forward hypothetical environmental issues and thereby enter the wealthier fields of research that directly address lay concerns, but is this a smart thing to do in the long term? Might it be more valuable to defend the idea that fundamental research is important? Even if -borrowing the words of Jacobi- its only objective is *"l'honneur de l'esprit humain"* (the honour of the human spirit). ■

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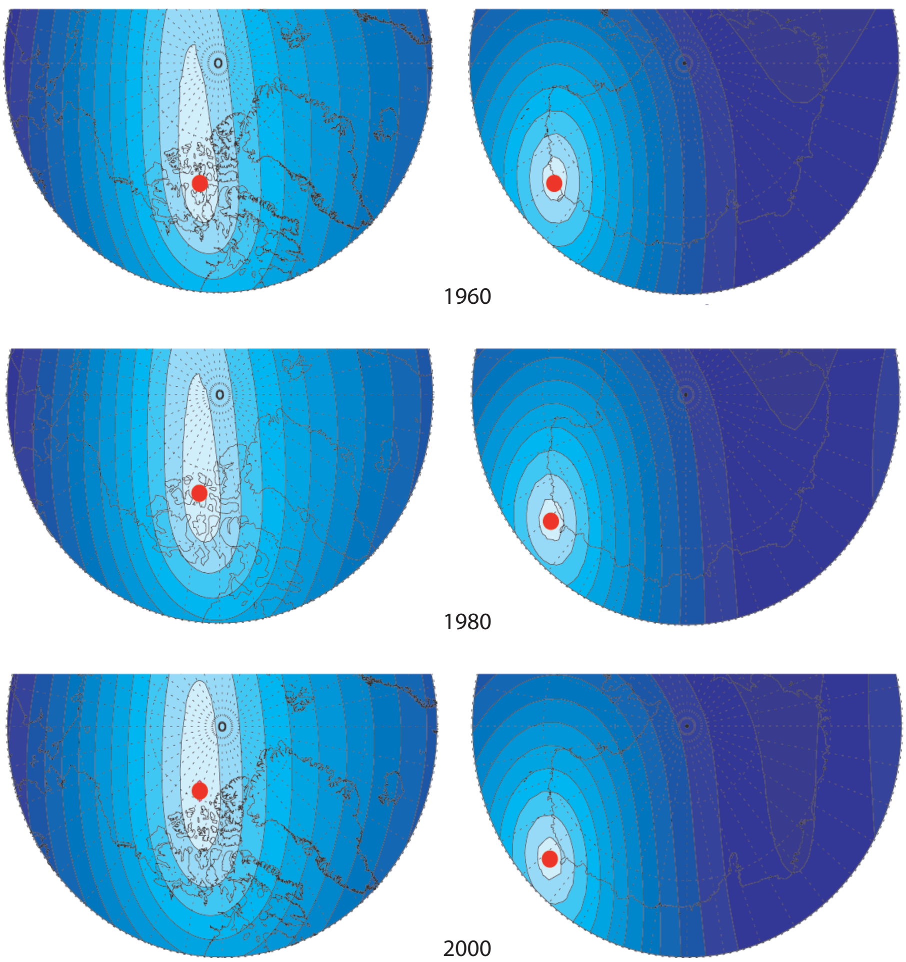

◀ **Fig. 3:** The Earth's dip poles represented by a red dot for epoch 1960, 1980, 2000. The rapid displacement of the north magnetic dip pole is clearly visible. Isovalues of the magnitude of the horizontal component of the field are also represented with increasing darkness of blue for increasing intensity (Mandea and Dormy, 2003).

First observation of direct CP violation in weak decays of neutral K mesons

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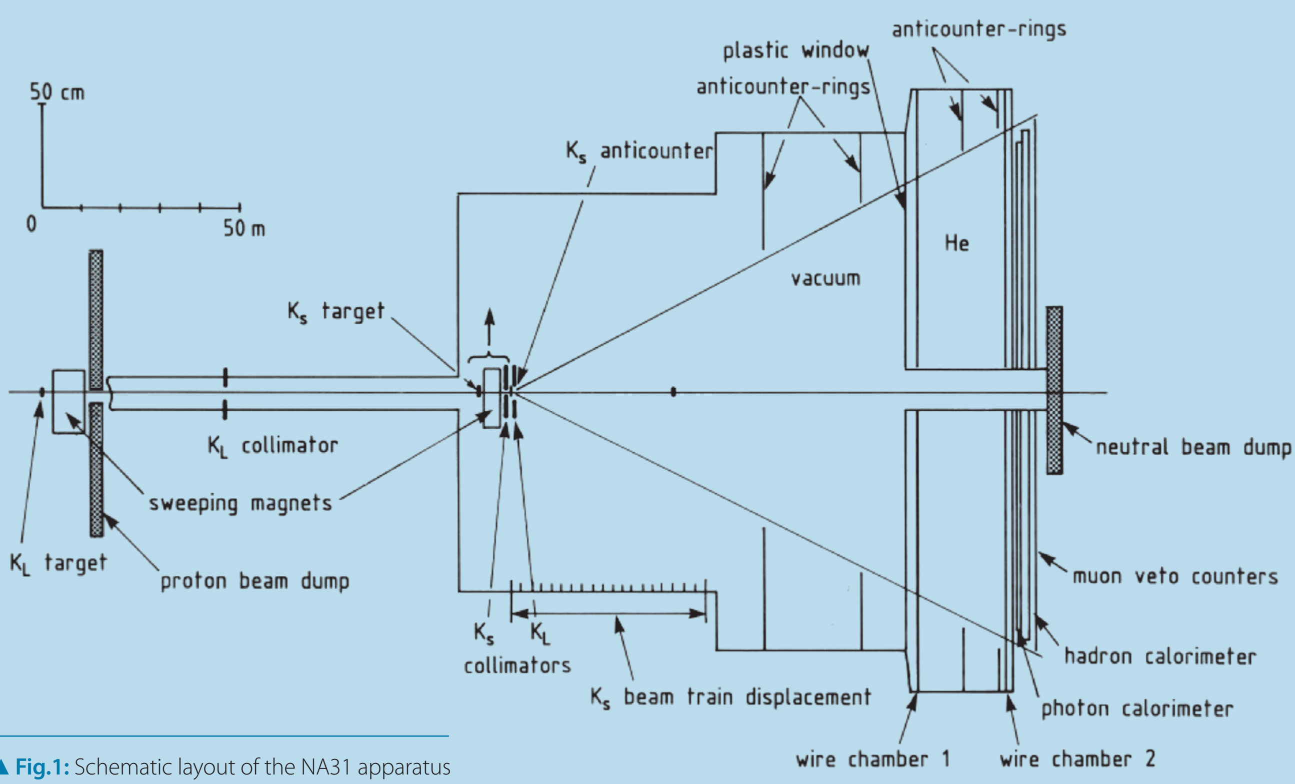
Symmetries and conservation laws have long played an important role in physics. The simplest examples of macroscopic relevance are the laws of conservation of energy and momentum, which are due to the invariance of forces under translation in time and space, respectively. Both are continuous transformations. In the domain of quantum phenomena, there are also conservation laws corresponding to discrete transformations. One of these is reflection in space (the "parity operation") ***P***. A second discrete transformation is particle-antiparticle conjugation ***C***. This transforms each particle into its antiparticle, whereby all additive quantum numbers change their sign. A third transformation of this kind is time reversal ***T***, which reverses momenta and angular momenta. It corresponds formally to an inversion of the direction of time. According to the C***PT*** theorem of Lüders and Pauli, there is a connection between these three transformations such that, under rather weak assumptions in a local field theory all processes are invariant under the combined operation C·***P***·***T***.

Fundamental interactions in particle physics obey symmetry laws. The strong and electromagnetic interactions are both symmetric under each of all three discrete mirror operations: spatial inversion or parity operation ***P***, particle-antiparticle inversion ***C*** and time reversal ***T***. Consequently, there are conserved quantum numbers like parity ***P*** and charge parity ***C***. A consequence is the prediction that the visible spectral lines from atoms and their antiatom partners are identical and cannot be used to identify antimatter in the Universe.

However, the weak interaction governing nuclear beta decay and related slow processes like the proton-proton fusion in the Sun, shows a violation of these conservation laws. Parity conservation was found to be broken in 1957, and the combined CP parity transforming a particle into its antiparticle is violated in decays of neutral ***K*** mesons, as discovered by Christenson, Cronin, Fitch and Turlay in 1964 [1].

K mesons carry a quantum number ***S*** called strangeness, which is conserved in strong interactions but can change in weak interactions. The neutral K^0 meson produced in strong interactions carries $S = +1$, while its CP-conjugate antiparticle $\overline{K^0} = CPK^0$ has $S = -1$. The eigenstates of CP are $K_1 = (K^0 + \overline{K^0})/\sqrt{2}$ with eigenvalue +1 and $K_2 = (K^0 - \overline{K^0})/\sqrt{2}$ with eigenvalue -1. If the weak interaction is invariant under CP transformation, the long-lived K_2 state cannot decay to a final state of two pions which have an eigenvalue +1 of CP. Since CP is not conserved in the decay of the long-lived kaons to two pions, the eigenstates of the weak interaction are no longer equal to the CP eigenstates. The physical states are then the long-lived state $K_L = K_2 + \varepsilon K_1$, and the short-lived state $K_S = K_1 + \varepsilon K_2$, with a complex mixing parameter ε whose modulus is about 2×10^{-3}. CP violating effects have subsequently been observed in the decay $K_L \to 2\pi^0$[5, 6], the charge asymmetry in K_L



▲ **Fig.1:** Schematic layout of the NA31 apparatus

$\rightarrow \pi^{\pm} e^{\mp} \nu$[3] and $K_L \rightarrow \pi^{\pm}\mu^{\mp}\nu$[4], the decay $K_L \rightarrow \pi^+\pi^-\gamma$[7], and more recently as an asymmetry between the decay planes of $\pi^+\pi^-$ and e^+e^- in $K_L \rightarrow \pi^+\pi^- e^+e^-$[8]. All these effects are successfully described by the mixing between K^0 and $\overline{K^0}$ strangeness eigenstates.

The origin of this CP violation remained unclear. Mixing can be due to the weak force or to a "super-weak" force as proposed ad hoc by Wolfenstein [2]. In the super-weak model the ratio of the decay amplitude for CP violating decays of K_L and K_S mesons to the amplitude for CP conserving decays equals the complex mixing parameter ε.

With three flavour generations CP violation can be incorporated in a natural way in the standard theory of weak interactions [9]. It is then possible that the CP odd eigenstate $K_2 = (K^0 + \overline{K^0})/\sqrt{2}$ can decay directly via weak interactions into a pion pair. This is dubbed "direct CP violation". A difference appears then in the CP violating decay rates of short- and long-lived neutral kaons into neutral and charged pions. The parameter ε' describing direct CP violation is proportional to the CP violating part of the decay amplitude of K mesons to the two-pion state with isospin 2. In the Kobayashi-Maskawa [9] model of CP violation ε' is in general not zero as opposed to the superweak model. The "experimentum crucis" is therefore to investigate whether ε' differs from zero.

The NA31 experiment

The NA31 experiment "Measurement of $|\eta_{00}/\eta_{+-}|^2$" was proposed by the CERN-Edinburgh-Mainz-Orsay-Pisa-Siegen collaboration to the SPS committee at the end of 1981 [10]. At the time of the proposal, estimates for $|\varepsilon'/\varepsilon|$ ranged from 10^{-3}[11] to 10^{-2}[12]. A difference in the CP violating decay rates of K_S and K_L to charged and neutral pions of the order of a percent or more could be expected and seemed measurable. The detector (Fig.1) employed wire chambers combined with calorimetry to determine the basic K^0 parameters such as energy and decay vertex with the precision required. A special feature was a K_S beam mounted on a train which was moved along the beam direction covering a 50 m K_L decay region with K_S decays (Fig. 2). Previous experiments had achieved an accuracy of about ten percent [13]. Experiments designed to reach the one percent level were in progress at BNL and FNAL [14].

The NA31 experiment aimed at an accuracy of a few parts in a thousand. The experiment was approved in autumn 1982, and took data in the years 1986-89 (Fig. 3).

The measured double ratio **R** of the four decay rates of K_S and K_L mesons to $2\pi^0$ and $\pi^+\pi^-$ final states was published in 1988 [15]. From the experimental result **R** = 0.980±0.004±0.005 the real part $\mathrm{Re}\,\varepsilon'/\varepsilon = (3.3\pm1.1) \times 10^{-3}$ was derived.

	Year	$\mathrm{Re}\,\varepsilon'/\varepsilon$	χ^2	
E731	1988	$(3.2\pm3.0) \times 10^{-3}$	0.32	[16]
NA31	1888	$(3.3\pm1.1) \times 10^{-3}$	(1.48)	[15]
E731	1993	$(0.74\pm0.6) \times 10^{-3}$	1.58	[17]
NA31	1993	$(2.0\pm0.7) \times 10^{-3}$	1.56	[18]
	Average	$(1.49\pm0.44) \times 10^{-3}$	4.94	

▲ **Table 1:** The 1993 average of $\mathrm{Re}\,\varepsilon'/\varepsilon$ for the NA31 and E731 experiments

The data accumulated during three years of data taking included a sample of 4×10^5 $K_L \rightarrow 2\pi^0$ events, two orders- of- magnitude more than in previous experiments. The statistical uncertainty on this event number is the largest error and determines the uncertainty of the result. The final results on $\mathrm{Re}\,\varepsilon'/\varepsilon$ of the NA31 experiment at CERN and the concurrent E731 experiment at Fermilab were published in 1993 [18, 17] and are displayed in Table 1.

The average is 3.4 standard deviations above zero with a confidence level of 18% for the consistency of the different measurements. This is a low but acceptable χ^2 probability. These measurements confirm that $\mathrm{Re}\,\varepsilon'/\varepsilon$ is nonzero and, therefore, that direct CP violation occurs in $K_0 \rightarrow 2\pi$ decays.

This view of the experimental situation was not shared unanimously, and it remained controversial for several years. Theoretical prejudice favoured the second E731 result which was in the range of the latest predictions from the Standard Model. Gluon penguin diagrams were originally assumed to dominate direct CP violation. The large mass of the top quark implied that electroweak penguin diagrams cancel the gluon contribution to a certain extent. This lead to a significant reduction the theoretical estimates combined with considerable uncertainties [19].

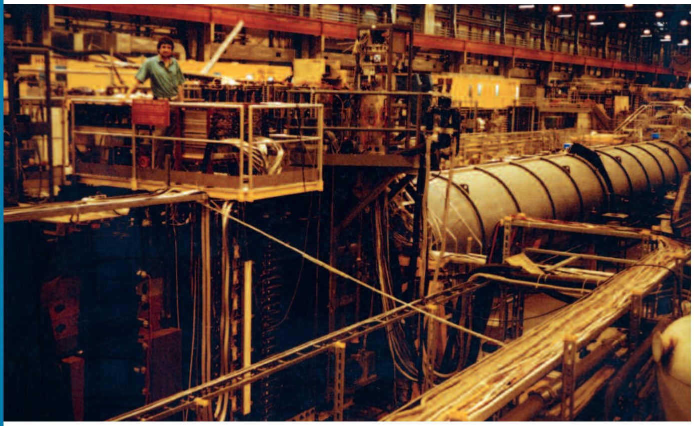
Subsequent experiments

In order to check the observation of the NA31 experiment, a new round of experiments was initiated in 1990 by the NA48 proposal for "A precision measurement of ε'/ε in CP violating $K_0 \rightarrow 2\pi$ decays", and by a proposal at Fermilab named KTeV. The measurement principle of NA48 was to a large extent exploiting cancellations in the double ratio. All four decay modes were collected concurrently in order to minimize differences in accidental activity and detection efficiencies.

The experiment was approved in 1991 and took data in the years 1997-2001. The higher beam intensity and the faster performance of the detector allowed a tenfold increase in the recorded event numbers compared to NA31. The leading statistical uncertainty comes from the number of 4.8 million registered $K_L \rightarrow \pi^0\pi^0$ decays.

The KTeV experiment at the 800 GeV/c Tevatron was the successor to the E731 experiment. K_S mesons were created from a slab of material inserted in a K_L beam by coherent regeneration, in one half of the beam cross-section. In the other half, the K_L beam

► **Fig. 2:** The "train" carrying the beam elements guiding the 450 GeV proton beam onto the target producing K_S mesons



▲ **Fig. 3:** Photograph of the NA31 detector

continued its way. This K_L "double beam" entered the decay volume upstream of the detector. All four decay modes were registered in the same exposure, and the number of recorded K_L decays to $\pi^0\pi^0$ was 3.3 million.

Conclusions about direct CP violation

After twelve years of experimentation and analysis, both experiments NA48[20] and KTeV [21] confirm a non-zero amplitude ε'. NA48 finds $\mathbf{Re}(\varepsilon'/\varepsilon) = (1.5\pm0.2)\text{x}10^{-3}$, and KTeV $(2.1\pm0.3)\text{x}10^{-3}$. Both experiments have definitively confirmed the original observation of the NA31 team that direct CP violation exists. The results of all published experiments on ε'/ε are shown in Fig. 4. The observed magnitude and sign of direct CP violation is at the level of theoretical predictions based on weak quark mixing. The experimental result for ε'/ε is rather precise already. However, the theoretical calculations of ε'/ε within the Standard Model, are still limited in their accuracy [22]. The main conclusion of the experiments is that ε' differs from zero and is positive, i.e. direct CP violation exists.

Taking into account the four relevant experiments NA31, E731, NA48 and KTeV, the weighted average comes out to be

$$\mathbf{Re}\left(\frac{\varepsilon'}{\varepsilon}\right) = (1.7\pm0.2)\,\text{x}10^{-3}.$$

If we call the amplitudes for the decays of the K^0 particle and its antiparticle $\overline{K^0}$ to a final state of two charged pions a and $\bar{a}$, then the asymmetry of the decay rates of particle and antiparticle, $\left(|a|^2 - |\bar{a}|^2\right)/\left(|a|^2 + |\bar{a}|^2\right)$ can be derived to be $2\mathbf{Re}\,\varepsilon' = (5.6\pm0.6)\text{x}10^{-6}$.

We conclude that this observation of direct CP violation definitely rules out the model invoking a new superweak force. On the other hand, this result is completely consistent with a mechanism for generating CP violation in the weak interaction via a complex phase in the Kobayashi-Maskawa quark mixing matrix. This view has been reinforced recently by the observation of a similar CP violating effect in the neutral B meson system.

However CP violation in the quark sector cannot explain the large matter-antimatter asymmetry in the Universe. In cosmology, a stronger CP violation, together with a large departure from thermal equilibrium and a baryon number violation could in principle lead to the observed baryon asymmetry. It remains an open question whether CP violation in the neutrino mixing matrix exists and could explain this enigma [23]. ■

About the authors

Konrad Kleinknecht studied physics at München and Heidelberg, 1966 Ph.D. on CP violating kaon decays; 1972-1984 Professor (Universität Dortmund); 1976 CalTech; 1984 Professor (Universität Mainz); 1988 Morris Loeb lecturer, Harvard University; Awards: 1990 G.W. Leibniz award of Deutsche Forschungsgemeinschaft, Bonn; 2001 Gentner-Kastler award and medal of SFP and DPG; Research: Weak interactions, CP violation, high energy neutrino scattering, electroweak interactions .

Heinrich Wahl obtained his PhD in nuclear physics at the University of Hamburg. Then he was working on meson photoproduction and $e+e$- interactions at DESY. Research at CERN focused on neutral kaon and hyperon decays, and high energy neutrino interactions. At present he is professor of physics at the University of Ferrara.

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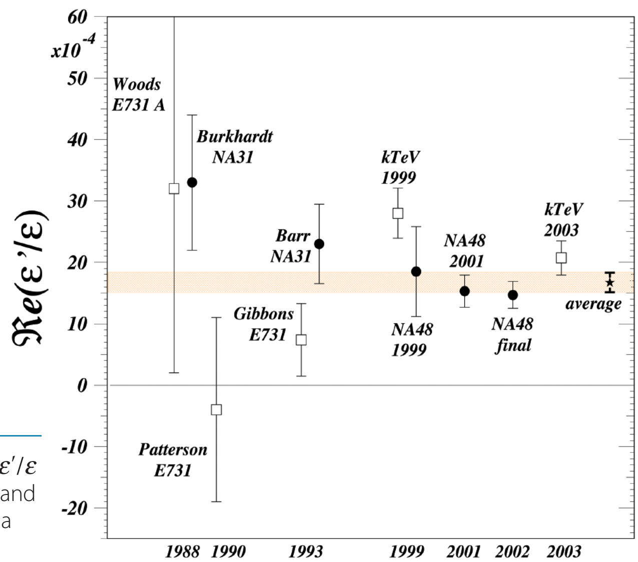

► **Fig. 4:** Time sequence of published measurements of the parameter $\mathbf{Re}\,\varepsilon'/\varepsilon$ of direct CP violation. The experiments at CERN are marked by filled circles and the experiments at Fermilab by open squares. The KTeV result from 2003 is a reanalysis of the data from the KTeV 1999 result.

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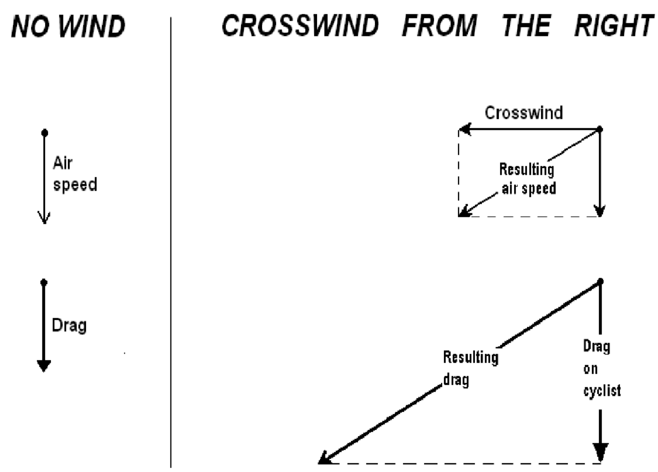
Physics in daily life: Cycling in the wind

L.J.F. (Jo) Hermans, Leiden University • The Netherlands

When riding our bicycle, wind is bad news, usually. For one thing, it spoils our average when making a round trip. The reason is obvious: we spend more time cycling with headwind than with tailwind.

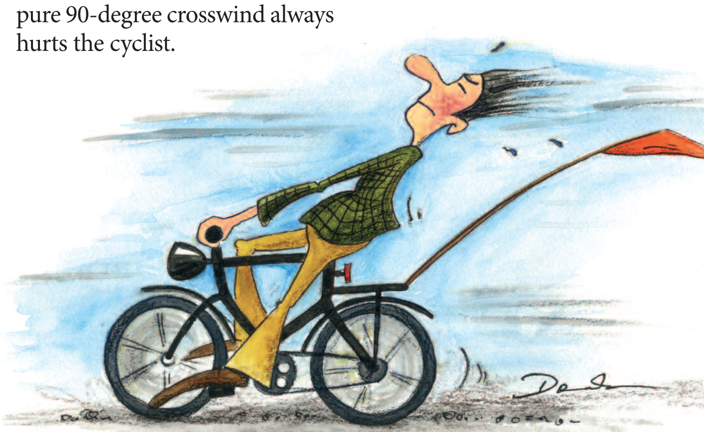
And what about a pure crosswind, blowing precisely at a right angle from where we are heading? That cannot possibly hurt the cyclist, one might think. Wrong. A crosswind gives rise to a much higher drag. Why is that? Don't we need a force in the direction of motion to do that?

So let us have a look at the relevant forces. The key is that air drag for cyclists is proportional to the relative air speed *squared* (just like for cars, *cf.* EPN 35/4, p. 130). This v^2 dependence spoils our intuitive feeling, as is easily seen from a vector diagram: See the figure, which illustrates the situation of a cyclist 'heading north'.



The figure says it all: In the wind-free case (left) the cyclist feels an air speed equal to his own speed, and experiences a certain drag which we may call D. With a crosswind blowing from the East, the resulting relative air speed is much larger, and so is the drag. In our example, the relative air speed is taken twice the cyclist's speed (it comes at a 60° angle from the right). Consequently, the resulting drag is $4D$. So its component in the direction of motion is $2D$, or twice what it was in the wind-free case.

In order to profit from the wind, it has to blow slightly from behind. Of course, the angle for which the break-even point is reached, depends on the wind speed relative to that of the cyclist. In our example, where their ratio is $\sqrt{3}$, the break-even angle is 104,5 degrees, as calculated by Fokke Tuinstra from Delft. But a pure 90-degree crosswind always hurts the cyclist.



In fact it's even worse. Also the relevant frontal area, which determines the drag, is increased dramatically. It is no longer that of a streamlined cyclist as seen from the front, but a *sin* α projection of the cyclist plus his bike. And with α being 60° in the example, this is practically the full side view of the bicycle and his rider. Even the crouched position does not help much in this case.

Clearly, riding our bike in the storm is really brave. It makes good exercise. And it yields some funny physics, too. ■

About the author

L.J.F. (Jo) Hermans recently retired as professor of Physics at Leiden University, The Netherlands. Main research topics: Internal-state-dependence of intermolecular and molecule-surface interactions, and nuclear spin conversion in polyatomic molecules. In the 1990s he served as a member of the EPS council.

About the illustrator

Wiebke Drenckhan (28) is a postdoctoral fellow at Trinity College Dublin, Ireland, where she is trying to unravel some of the mysteries of the physics of foams and other complex systems. Much of her spare time is invested into sharing her views on science from a slightly different perspective, namely that of a cartoonist.

An interview with Sir Anthony Leggett

In the summer of 2005 Professor Leggett visited the University of Lisbon where he gave a seminar and public lecture. The visit was organised by the Centro de Fisica Teorica e Computacional following the 'tradition' of inviting a renowned physicist to close the academic year's activities. His predecessors were Professor Eric Cornell (2003) and Professor Pierre Gilles de Gennes(2004), recipients of the Nobel Prize for Physics in 2001 and 1991, respectively.

During the visit Professor Leggett was interviewed by Patrícia Faísca of the Centro de Física Teorica e Computacional da Universidade de Lisboa and by Pedro Patrício of the Centro de Fisica Teorica e Computacional da Universidade de Lisboa e Instituto Superior de Engenharia de Lisboa.

After completing your degree in Classics at Balliol College in Oxford, you decided to take a second undergraduate degree in sciences. Why? And why physics?

I think I was probably just very unimaginative and it really didn't occur to me that I should try to find a career outside academia. I had no experience on anything else at that stage and academic life really seemed the most obvious option. During my Classics course I had concentrated mostly on philosophy, which was something that I was most interested in and that I, in some sense, most enjoyed. But as I started to contemplate going on to a full time academic career in philosophy I realised that I didn't want to do it. And then I started asking myself why exactly I didn't want to do it, and I was sufficiently unimaginative that it didn't occur to me that maybe my problem was with academic life as such and so it had to be something wrong with philosophy as such. The more I thought about it, the more it seemed to me that basically what counted as good or bad work in philosophy depended so much on the precise term or phrase that you used, and the particular examples you chose, and it seemed to me that this was all somehow very subjective. And I really feel comfortable with a field of study where, in some sense, Nature will tell you whether what you are doing is right or wrong. I knew very little about physics in those days but I had had a slight encounter with it: I studied things on the edge of physics, for example, I remember during my degree in Classics I looked at things like Zeno's paradox; so I had some vague idea about what physics was about and it seemed to me that it was the kind of field where I would somehow feel much more comfortable and happier.

Was your original undergraduate training in Classics useful in your scientific academic career?

Yes, it was very useful. In some sense, all of it was useful and particularly useful was the philosophy part. I think that if you go through a course of analytical philosophy-I'm very conscious that philosophy means different things in different parts of the world-but in the Anglo-Saxon tradition, a degree in philosophy is very highly analytical, and if you go through it you do became much more conscious of the implicit assumptions that you're making in your work. I do feel that one benefit I had from this is that - more than a lot of my colleagues in physics who hadn't had this kind experience-I'm conscious of the implicit assumptions I'm making.

Do you think your early training in Classics influenced your research in the conceptual foundations of quantum mechanics?

Yes, certainly, very much so as regards the philosophy component. To be quite honest, in the first few years when I was doing physics, I was not particularly interested in the foundations of quantum mechanics. Then I had a colleague at the University of Sussex, Brian Easlea, who had started life in physics but gradually wandered off to history and social studies of sciences, and he gave a little course of lectures, a mini-course, on the Quantum Measurement Problem. I guess that was what really persuaded me that it was something that was worth thinking about. Probably it was by the end of the 1960s that I really started thinking about it, but I was not able to do anything for another 10 years or so, my first paper on the foundations of quantum mechanics appeared in 1980. There's a whole generation, I would say, roughly from let's say late 1930s to perhaps the early 1970s, when the whole subject was almost taboo in the Anglo-Saxon countries but it is interesting that in the Mediterranean countries of Europe it never became taboo. People were always interested, even in those years. But I suspect I would never have got interested myself were it not for my education in philosophy.

When have you become interested in the work that was recognized in 2003 with the Nobel Prize, namely the theory of superfluid liquid ^{3}He?

My PhD degree had two parts: one was connected with the interaction of phonons in liquid helium 4, so it hadn't much to do with it directly. The second part was a study in the context of the Landau-Fermi liquid theory. The latter was published in 1957, I think, and in 1961, when I started, because of the delays in translation, the Landau-Fermi theory was still not widely known in the West. I knew it because one of the great pieces of advice that my adviser Dirk ter Haar gave me, at a very early stage, was 'make sure you know enough Russian to read things in the original'. That was a very useful advice and I read all the Russian papers on Landau-Fermi liquid theory when they first came out and I was quite impressed by that, quite interested in it, and the second half of my DPhil thesis was on the helium-3 helium-4 phase diagram. You have to remember that, in those days, the phase diagram of helium-3 helium-4 mixtures had been explored only at quite high temperatures. People knew there was a phase separation but they didn't know how it would go at lower temperature, in particular they didn't know whether a small amount of helium-3 would be stable in helium-4 at zero temperature or vice-versa or both. I chose the helium-3 region of the diagram and looked at dilute solutions of helium-4 in helium-3. This was the wrong guess because the phase separation curve basically hits the axis on that side. The other side is much more interesting, and years later Bardeen, Bahm and Pines did some very interesting work on that.

What is the importance of superfluid ^{3}He?

From a purely immediate practical point of view superfluid helium-3 is probably the most useless system ever discovered. However, from a more indirect point of view, it is really quite significant because it is the most sophisticated physical system which we can currently claim a quantitative understanding of. We believe that we do understand a great deal of what goes on in superfluid helium-3. Some very interesting and almost unique phenomena do go on, some of which have analogues in other systems with more direct practical application, for example, high-Tc superconductors. I think it's probably fair to say that by trying to understand the properties of superfluid helium-3 we have a lot of spin-offs for these other systems. For example, we can apply some of the ideas developed there to the early universe and to particle physics.

Can you tell us about one of your other research interests, namely the theories and experiments aimed at testing the limits of quantum mechanics? What is the state-of-the-art in the field? Do you think that the next generation of experiments will 'see' the 'failure' of (our understanding of) quantum mechanics?

This is something I'm certainly been trying to push for the last twenty-five years. One of the explicit suggestions I made was to look for the effects of superposition of different flux states in an rf-SQUID set up. You have two SQUID rings, two states which are nearly degenerate. In one of them the current is going clockwise with an amplitude of, say, a few micro amps, and in the other it is going anticlockwise. Could you actually set up an experiment to look for the effects of interference between these two states? The reaction I got from quite a large part of the quantum measurement community in those days was: this is complete nonsense, everyone knows that by the time you get up to this kind of macroscopic level decoherence is going to kill you stone dead, you are not going to see any interference. So, we had to work quite hard fighting these objections, we published quite a few technical papers in the 1980s on this. Then, out of the blue, along came quantum computing (QC), something we certainly hadn't foreseen at all, and this meant that all these experiments which were done on a shoestring previously, now have no trouble attracting funding from the QC program. So, over the last five years a number of these experiments have been done and what's ironical is that the people who came into the field in the 1990s are complaining that the degree of coherence in the Q-factors of these SQUIDS is only 300! In 1980 most people didn't believe in it all, so I think it's quite amusing.

Can you explain quantum decoherence and how it may compromise the future of quantum computing?

Well, it may or not, we don't know. The sort of general trend of the argument which people have used about decoherence is right in the sense that the more complicated you make the system and the more interaction it has with its environment then, by and large, the higher the degree of decoherence it's going to be subjected to the more difficult it's going to be to make it operate as a qubit. What, maybe, these arguments tend to forget, or at least did in the past, is that there is always some kind of specific reason for why you get decoherence: there is an interaction with a particular kind of degree of freedom of the environment and if you can just isolate that and, possibly eliminate it, then you're in business! And that's exactly how these recent experiments have worked; they basically thought about the possible mechanisms for decoherence and one by one have eliminated them. So, in the end you have up to a Q-factor of 300, even in the original arrangement that I proposed, which was completely unexpected as recently as 6 years ago. And it seems there is no reason in principle why it won't get a lot better. So, at least from the point of view of this simple, sort of common or garden, decoherence, there is no reason why a quantum computer will not work. In fact, even a quantum computer built out of SQUIDS may well work. But there are more subtle things which I think we will not know until we actually start building a working quantum computer. I believe there is a class of effects associated with virtual transitions via the environment which have not properly been looked at so far, and that by definition won't occur at the level of a single qubit or even 2 qubits or three. It's only when you go to very large numbers that these effects may play a role and then they could be extremely destructive. I actually have a student who will hopefully look at that question. We believe it's something which hasn't been dealt with properly in the past. If you asked me about the future of quantum computing, say in 10 or 15 years, I would guess that it will look like controlled thermal nuclear fusion does right now. In other words, the basic principle seems ok, there is absolutely no overarching theoretical reason why it won't work. But it's just such a pain to put all the bits together that people are going to ask: What is it worth to factorise a five hundred digit number? And the answer is not infinity! I mean it's very large but not infinity! And they may decide it's just not worth it.

According to Arnol'd, the Russian mathematician, "the only computational experiments worth doing are those that yield a surprise". What do you think is the role of computer simulations in physics?

I think it basically allows us to implement a lot of ideas that we've had in a qualitative sense, and that we have been able to work qualitatively. And we want to know quantitatively how good they are. Within my field, one very nice example of that is liquid helium-4. People like Landau and Bogoliubov had a lot of very fruitful qualitative ideas but it has never been possible to implement them quantitatively by any known analytical technique. What was really quite revolutionary, as shown by people like my colleague David Ceperley, at the University of Illinois, is that you can actually use computational techniques to generate numbers, for example for the excitation spectra of helium-4 that may be compared with experiments, of normal fluid densities as a function of temperature, and thus tested. The degree

Vita

Anthony J. Leggett, is the John D. and Catherine T. MacArthur Professor and Center for Advanced Study Professor of Physics, and has been a faculty member at the University of Illinois at Urbana Champaign since 1983. He is a leading scientist in the theory of low-temperature physics, and his pioneering work on superfluidity was recognized by the 2003 Nobel Prize in Physics. Professor Leggett has shaped the theoretical understanding of normal and superfluid helium liquids and other strongly coupled superfluids. He set directions for research in the quantum physics of macroscopic dissipative systems and in the use of condensed systems to test the foundations of quantum mechanics. His research interests lie mainly within the fields of theoretical condensed matter physics and the foundations of quantum mechanics. He has been particularly interested in the possibility of using systems, such as Josephson devices, to test the validity of the extrapolation of the quantum formalism to the macroscopic level; this interest has led to a considerable amount of technical work on the application of quantum mechanics to collective variables and in particular on ways of incorporating dissipation into the calculations. (Further information is available from www.physics.uiuc.edu/People/Faculty/profiles/Leggett/).

In 2004 Professor Leggett was awarded a knighthood (KBE) for "services to physics" in the Queen's Birthday Honours list. A detailed autobiography may be found at http://nobelprize.org/physics/laureates/2003/leggett-autobio.html.

of agreement is really quite satisfying. And this is not something you could have done analytically.

What are your views on interdisciplinary research?

I think that interdisciplinarity is a much oversold concept. Let me make clear what I mean by that. I don't think interdisciplinarity is a sort of 'sauce' that you pour on a whole lot of ingredients which somehow improves it. In a problem which requires the expertise of a number of disciplines interdisciplinarity is going to happen quite automatically. Take for example the field of high temperature superconductivity. From the moment these materials appeared on the scene, it was obvious you had to have physicists, chemists, material scientists etc., collaborating on this. And they did. No one had to come along and say: we'll give you 500 million dollars extra if you can demonstrate that you have interdisciplinarity. It just happened in the natural course of events. Just look at the problem: does it require an interdisciplinary approach? If so, go out and find people to work with you. Don't be into interdisciplinarity just for the sake of being interdisciplinary. It does not make any sense.

There is an increasing number of physicists working outside the traditional areas of physics (biology, economics, and social sciences). How do you feel about this?

Certainly it is a very worthwhile thing to try but- and I have seen this happen quite a bit in the field of biological physics- there is a great temptation, for example if you come from the field of statistical mechanics, to simply go out, look at an area of biology and try to find yourself a problem which can be done with, or seems to be attackable with the kind of techniques you learnt in statistical mechanics. You solve the problem, you publish several papers on it and then you find that your colleagues in biology are just not interested. It does not seem a very important problem. If you are actually anyone who is going to do this kind of thing it is very important that you talk to the people who are and have already been in the field for years and have some kind of feeling for what the really significant problems are. Of course, what you are liable to find is that these are not the kind of problems that you could attack with your traditional methods, but nevertheless, you may have a somewhat generic kind of background which enables you to look at them.

Many people say that biology is the science of the future. Would you agree?

I would say our understanding of the workings of the brain today is almost certainly no better, in fact it is probably worse, than was our understanding of matter at the atomic level in the late 19th century. I think it is entirely conceivable that the 21st century will bring the same kind of major revolution as we saw in physics in the 20th century in that area and certainly the challenge is at least as great. I may actually add one thing which will probably shock you: I actually think that it should not be totally disreputable for physicists to study what are called paranormal phenomena. In paranormal phenomena there are a variety of things from card guessing experiments to speculations about an after life. It is obvious that in many of these areas there is a lot of charlatanism, and a lot of self-deception, but that does not mean that there is nothing there. You have to remember that, say in the 15th century, there were lots and lots of things which we now think of as alchemy. Most of them were rubbish, but underneath it, there was a core of what we know as chemistry. I wouldn't consider as totally unconceivable that some of these phenomena, which today we regard as a sort of fiction, completely paranormal, to turn out to have some real scientific basis. In particular, I would say those phenomena which we exclude not because of the 1st law of thermodynamics but because of the 2nd law. I think those are the ones which we probably need to look at harder. Returning to your original question, I think that what makes the problem of the brain, specifically of neuropsychiatry, almost unique is that it combines a huge and immediate human relevance with very challenging scientific importance.

◀ Anthony J. Leggett receiving his Nobel Prize from His Majesty the King at the Stockholm Concert Hall.

Will you tell us about your favourite popular science book?

I think there are a couple of rather good books. There has been dozens of books coming out over the last ten years on the conceptual problems of quantum mechanics that range from very good to absolutely awful. There are two which I think are especially good and I would certainly recommend to anyone who wants to find out about this field. One is by Nick Herbert. It is quite old now, it's from1986, it is called "Quantum reality". That is a very nice book. It pulls no punches, it is written at a level which ought to be accessible to anyone with basic arithmetic and not much more. A second book in the same general vein is Gerard Milburn's recent book which is called the "Feynman processor", about quantum computing. I think it is a rather good book though it does actually put quite tough demands on the reader. It is rather amusing because there is this famous statement which Stephen Hawking attributes to one of his editors: "that every equation you put in the book halves its sales". This is a joke that Gerard Milburn took extremely seriously and he didn't put a single equation in his book, but it does require the reader to understand that $(-1)^0$ is plus one. I think this book is very good, very nice.

If you were back in the 1960s finishing your Classics degree in Oxford, would you still take a second undergraduate degree in physics?

Possibly, but I think, knowing what I do now, I would more likely take it in something like neuropsychiatry. I really do think that that is going to be the field at least in the 21st century which will be looked back on as really exciting. Physics is still regarded as very substantial, but it won't have quite the same degree of excitement. Again, neuropsychiatry clearly is much more useful in a sense that most of physics is not. ■

Visit the CNAM Museum in Paris

Etienne Guyon,
Ecole Supérieure de Physique et Chimie Industrielle de Paris

There are several places devoted to science in Paris such as the large "Cité des sciences" (City of Sciences) in the north-west or the "Palais de la Découverte" (Palace of Discovery) near the Champs-Elysées. Here I would like to draw your attention to another place, which is devoted to the history of techniques, that is, in fact, to centuries of applied physics.

In the true heart of Paris, the old monastery of Saint Martin des Champs (Saint Martin in the Fields!) has hosted the Conservatoire des Arts et Métiers (CNAM, the National Museum of Arts and Crafts, www.arts-et-metiers.net) for more than two centuries. On the one hand, it works as a technical and engineering school where students and working people can attend daytime and evening lectures preparing to various diplomas. On the other hand, it is a museum, which has been recently renovated and is worth a visit for its treasures of original pieces of technology covering more than three centuries of human achievements.

In the second half of the 18th century — the "siècle des lumières" (the enlightenment century) — les "cabinets de physique et de curiosité" (private rooms in which the upper class was doing or looking at various experiments in mechanics, physics or chemistry) started to multiply. They were the true ancestors of the CNAM. There, the clergyman Nollet performed experiments on electricity, and Lavoisier attended some of his demonstrations. In these early times, other subjects such as thermometry, osmotic pressure… were also presented. Following the spirit of the "Encyclopaedia", Vaucanson started in 1783 to gather tools and machines for the education of craftsmen and, quite naturally, the project of a "conservatoire pour les arts et métiers" came from the Revolutionary Assembly (the "Convention") in 1794. The founder of CNAM was a clergyman member of the Assembly, Henri Grégoire (l'abbé Grégoire). He presented the project[1], which provided clues of which some are still valid in today CNAM. It associated exhibition with education through the presentation of machines, which circulated from the rooms where they were stored to the classrooms and back. It stated that the machines should work, for demonstrations. Finally it dismissed the accumulation of objects within the Museum.

Now, the mission of permanent education of CNAM and the museum itself are dissociated. In the museum are shown the most famous and precious objects (about 5000 of them) representative of the evolution of ideas and techniques from the 18th century to the achievements of today's technology: information technology, optics, energy, transportation, and their applications in daily life (I am personally involved in an exhibition on concrete). The systematic collection of 80 000 objects is located in Saint Denis (north of Paris); it is also worth being seen by specialists.

▲ Below the wing of Clement Ader plane (date: 1897)
© CNAM, P. Faligot

By all means, a visit to CNAM is "a must" in Paris, from the "Fardier de Cugnot" (the first automobile constructed in the world), the automatons of Vaucanson, the weaving machines of Jacquard, to more recent collections. There are so many treasures from all ages, including the beautiful site of the chapel Saint Martin des Champs where the Foucault pendulum hangs, the calculating machine of Pascal and the first plane which crossed the Channel... ■

[1] « La création d'un Conservatoire pour les Arts et Métiers, où se réuniront tous les outils et machines nouvellement inventés ou perfectionnés va éveiller la curiosité et l'intérêt, et vous verrez dans tous les genres des progrès très rapides. Là, rien de systématique : l'expérience seule aura droit à l'assentiment… On évitera l'accumulation des machines inutiles… L' enseignement, placé à côté des modèles, exige des démonstrations… » which translates into : "The creation of a Museum for Arts and Crafts where the newly invented or improved tools and machines are collected will raise curiosity and interest, and you will see rapid progress in all fields. There will be nothing systematic: only the experiment will be accepted… The accumulation of useless machines will be avoided… Teaching, close to such models, requires demonstrations…"

◀ The "Fardier de Cugnot", the first vapour driven vehicule (date: 1771)
© CNAM, photo P. Ballif

Astronomy: Principles and Practice, 4th Edition

Those familiar with earlier editions of this book can be assured that the customary clarity and attention to detail has been maintained. Together with its companion volume 'Astronomy: the Structure of the Universe' the book under review provides an introduction to astronomy suitable for a first-year undergraduate course at a British university.

Areas which are especially useful and which are treated with particular thoroughness are spherical geometry and trigonometry (Chapter 7), coordinate systems (Chapter 8), timekeeping (Chapter 9), the description of classical measurements of the solar system (Chapter 10), stellar aberration, precession of the equinoxes and nutation (Chapter 11), a history of the development of views of the solar system from the time of Ptolemy (Chapter 12), celestial mechanics and interplanetary transfers (Chapters 13 and 14), optical telescopes (Chapters 16 and 17), optical detectors (Chapter 18), radio telescopes (Chapter 21) and 'high energy' instruments (Chapter 23). This list also provides a good indication of the scope of the text, which is almost identical to that of the previous edition. There are plenty of examples interspersed within the text and each chapter ends with a range of relevant exercises.

The format and content of the book follow closely those of the 3rd edition and the most obvious changes are merely rearrangements of some of the material amongst chapters. The first five chapters are identical in each edition. At first sight Chapter 6, entitled 'The Night Sky', is new but in fact it contains material from the old Chapter 24.

The chapters of the 4th edition adding new material to that of their counterparts of the 3rd edition are as follows: Chapter 7 has a discussion of GPS satellites, Chapter 9 includes a discussion of the relationship between Dynamic Time and International Atomic Time, Chapter 13 includes a section on solar radiation pressure and Chapter 14 a very useful one on chaos and unpredictability in relation to the calculation of the orbits of comets, meteors and asteroids. In Chapter 15 the section on basic spectrometry contains sub-sections on natural line width and line broadening mechanisms. Again, though quite a lot of other material in this chapter seems new it has been transferred from earlier chapters of the older edition. Chapter 16, 18 and 19 respectively have descriptions of photon shot noise CCDs, and Fabry-Pérot spectrometry.

As might be imagined the chapters containing most of the new material are the later ones – Chapters 20 (Modern telescopes and other optical systems), 21 (Radio telescopes) and 24 (Practical projects). Chapter 20 contains much new material on recent developments in ground-based visual astronomy such as active and adaptive optics, aperture synthesis and intensity interferometry. The chapter title has been changed to reflect this. In the chapter on radio astronomy the section on interferometry has been expanded to include VLB interferometry and a more detailed discussion of aperture synthesis. The last chapter – 'Practical projects' covers interesting and informative new projects concerned with radio astronomy, sunspots and the moon. Following the final chapter there is a two-page list of relevant websites.

In summary this is an excellent book on astronomy but owners of a copy of the equally excellent third edition may feel that apart from a rearrangement of some of the original material between chapters (which in my view adds nothing to the logical development), there is not sufficient difference in the form of genuinely new material to warrant further expenditure. However, if you do not possess a copy of the third edition and you require a book introducing the principles and practice of astronomy at first-year undergraduate level with every detail explained then this is the one for you. ■

Ian C. Malcolm,
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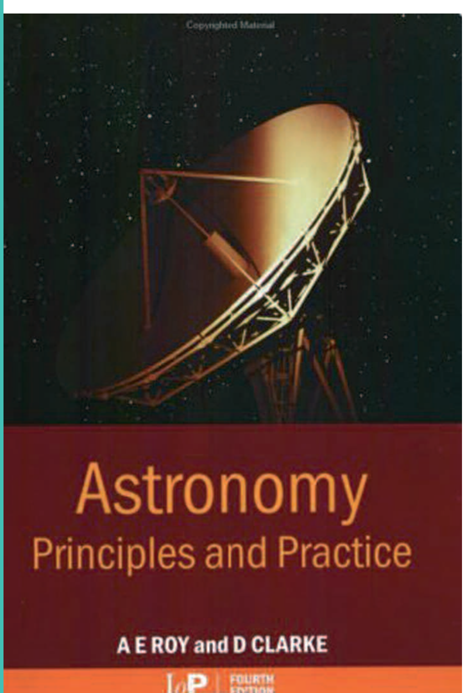
A.E. Roy and D. Clarke,
Institute of Physics, 2003. 475 pages.



Book available for review

Astroparticle physics
C. Grupen, Springer 2005, 441 pages

6th Conference on dynamical systems - theory and application proceedings
J. Awrejcewicz, J. Grabski, J. Nowakowski, 2002

A course in modern mathematical physics
P. Szekeres, Cambridge 2004, 589 pages

A first course in string theory
B. Zwiebach, Cambridge 2004, 558 pages

A modern introduction to quantum fiels theory
M. Maggiore, Oxford University Press 2005, 291 pages

Alternative logics, do Sciences need them?
P. Weingartner, Springer 2004, 367 pages

An introduction to galaxies and cosmolology
M.H. Jones and R.J. A. Lambourne, Cambridge 2004, 435 pages

Analytical mechanics for relativity and quantum mechanics
O. Davis Johns, Oxford Graduate Texts 2005, 597 pages

Asymptotic giant branch stars
H. J. Habing, H. Olofsson, Springer 2004, 559 pages