europhysicsnews

36/1
2005
January/February 2005
Institutional subscription price:
99 euros per year

FEATURES ISSUE

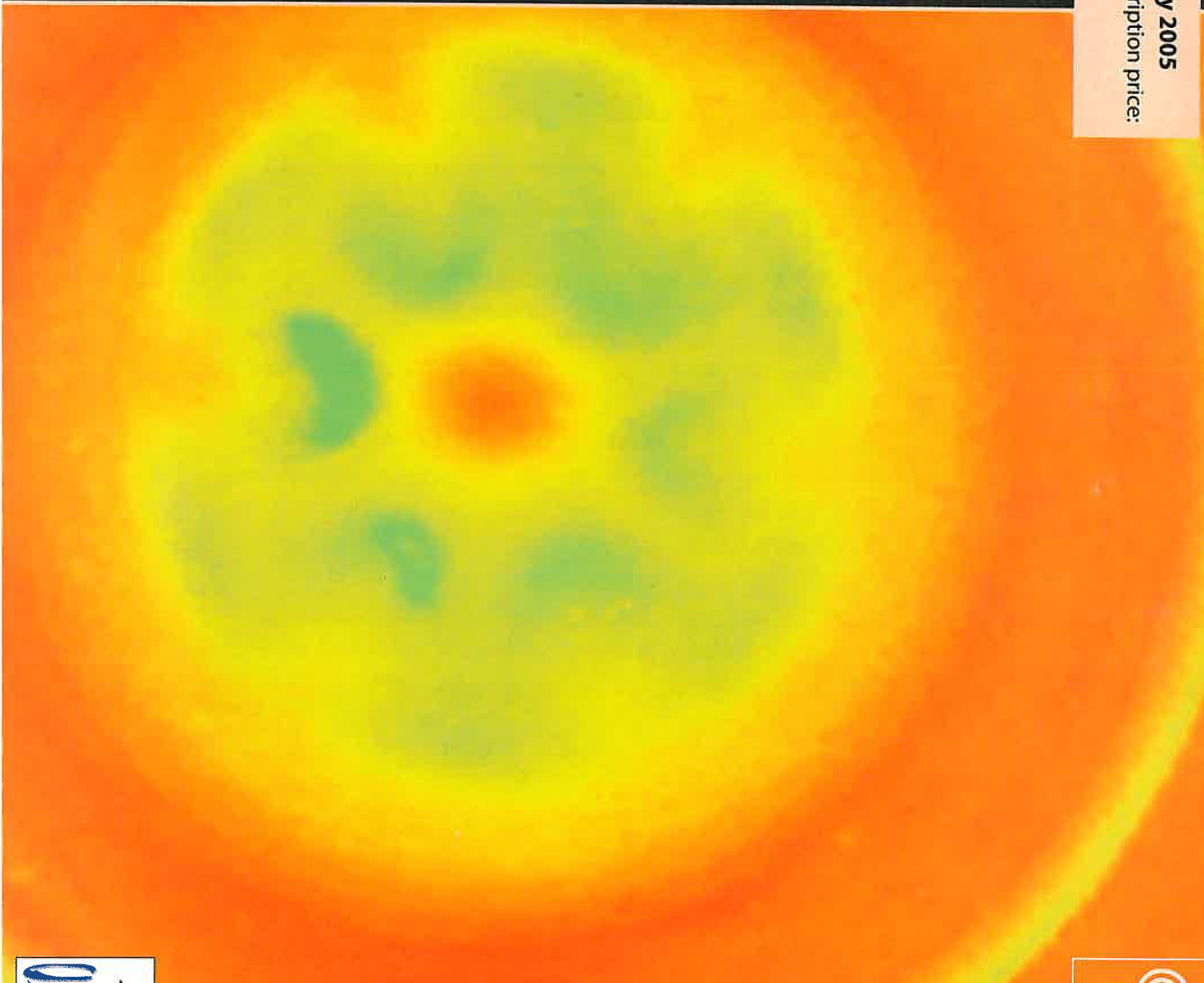
Drops that buckle

Ternary and quaternary fission

Quantum computers : where do we stand?

Neutrino mass, radioactivity and the dating of wine

features

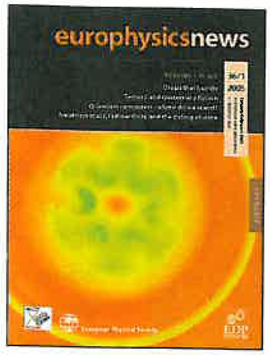


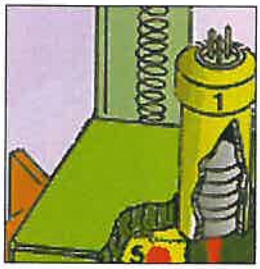
European Physical Society

EDP SCIENCES

europhysicsnews

Volume 36 Number 1
January/February 2005





▲ PAGE 6
Slippery Nanoworld

▲ PAGE 9
Drops that buckle

▲ PAGE 27
Old ears

contents

FEATURES

NEWS, VIEWS AND ACTIVITIES

europhysicsnews

europhysicsnews is the magazine of the European physics community. It is owned by the European Physical Society and produced in cooperation with EDP Sciences. The staff of EDP Sciences are involved in the production of the magazine and are not responsible for editorial content. Most contributors to **europhysicsnews** are volunteers and their work is greatly appreciated by the Editor and the Editorial Advisory Board.
europhysicsnews is also available online at: **www.europhysicsnews.com**

36/1
2005

January/February 2005
Institutional subscription price:
99 euros per year

Editor — **David Lee** EMAIL: d.lee@uha.fr

Science Editor — **George Morrison** EMAIL: g.c.morrison@bham.ac.uk

Designer — **Xavier de Araujo** EMAIL: designer@europhysnet.org

Directeur de la publication — **Jean-Marc Quilbé,** EDP Sciences

Schedule

Six issues will be published in 2005. The magazine is distributed in the second week of January, March, May, July, September, November. A directory issue with listings of all EPS officials is published once a year.

Production and Advertising

Agnes Henri
Address EDP Sciences,
17 avenue du Hoggar, BP 112,
PA de Courtabœuf,
F-91944 Les Ulis Cedex A, France
Tel +33 169 18 75 75
Fax +33 169 28 84 91

Printer Rotofrance, Lognes, France
Dépôt légal: janvier 2005

Subscriptions

Individual Ordinary Members of the European Physical Society receive **europhysicsnews** free of charge. Members of EPS National Member Societies receive Europhysics News through their society, except members of the Institute of Physics in the United Kingdom and the German Physical Society who receive a bimonthly bulletin. The following are subscription prices available through EDP Sciences. **Institutions** 99 euros (VAT included, European Union countries); 99 euros (the rest of the world). **Individuals** 58 euros (VAT included, European Union countries); 58 euros (the rest of the world). Contact subscribers@edpsciences.com or visit www.epdsciences.com

ISSN 0531-7479
ISSN 1432-1092 (electronic edition)

Address EPS, 6 rue des Frères Lumière,
BP 2136, F-68060 Mulhouse Cedex, France
Tel +33 389 32 94 40 **Fax** +33 389 32 94 49
Web www.eps.org

The Secretariat is open 08.00–17.00 CET except weekends and French public holidays.

EDP Sciences

Managing Director	Jean-Marc Quilbé

Address EDP Sciences, 17 avenue du Hoggar, BP 112, PA de Courtabœuf, F-91944 Les Ulis Cedex A, France
Tel +33 169 18 75 75 **Fax** +33 169 28 84 91
Web www.edpsciences.org

Be ready: the International Year of Physics is taking off!

Martial Ducloy, EPS Past-President

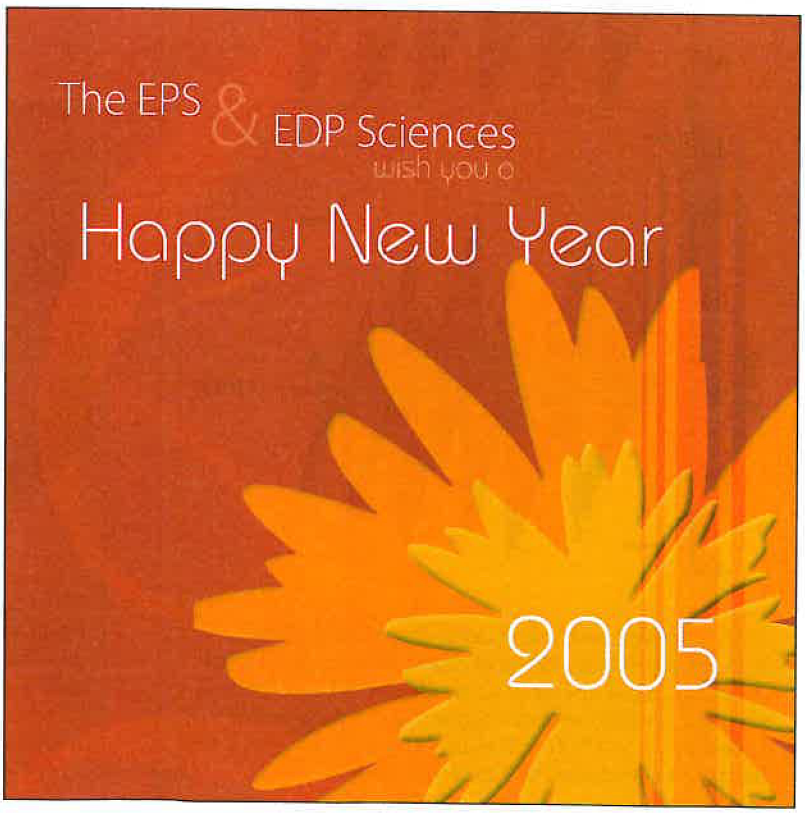
It has been a long and hard way since the European Physical Society proposed in late 2000 to declare 2005 as the "World Year of Physics" (WYP). This initiative has steadily made progress in its acceptance by the international organisations. The IUPAP endorsed it in October 2002, at its General Assembly in Berlin. The General Conference of UNESCO voted to accept it in Paris, in October 2003. Finally, in June 2004, in New York, the General Assembly of the United Nations Organisation passed by acclamation a resolution declaring 2005 as the "International Year of Physics" (IYP) (see: www.un.org/Depts/dhl/resguide/r58.htm and www.un.org/News/Press/docs/2004/ga10243.doc.htm.). At that point, one should recall that only the UN General Assembly has the power to declare "International" years. So the "World Year of Physics" is now the "International Year of Physics"! The UN resolution on IYP has been sponsored by the permanent delegations of Brazil, France, Lesotho, Monaco, Portugal, Singapore and the United Kingdom, and presented by the Lesotho ambassador to the UN, Dr. Lebohang K. Moleko (see: www.un.org/webcast/ga.html). Dr Moleko should be thanked for his efforts to get the resolution passed.

In the mean time, physicists and Physical Societies did not wait for the vote of the resolution at the UN assembly to start to plan and organise events, actions, exhibits and conferences at the national and international level. Two WYP preparatory meetings were held in Graz (July 03) and Montreal (March 04), in which many events planned worldwide have been presented – see the report on the Montreal meeting by Christophe Rossel, in *Europhysics News 35/3*, p. 96, 2004. More recently, in October 2004, the European WYP coordinators met in Mulhouse to present their activity plans, to share their experience and to try to coordinate events between European countries as much as possible. The level of preparation of WYP activities was found to be quite advanced: museum exhibits for the general public around Einstein's legacy and physical sciences in general, radio and television programmes, commemorative coins and stamps, street events on physics themes, theatre plays, conferences, etc. In Portugal, a coordinator in charge of WYP relations and organisation has been officially accredited by the Portuguese government. Also, more global activities, at the European level and worldwide, are well on the way. These include activities such as "physics enlightens the world" (a relay of light signals around the globe), "physics talent search", and "physics as a cultural heritage" (a full account of those global initiatives is given on the web page www.wyp2005.org/). Funding for WYP activities is also growing quickly both at the local and European level: the European Commission has recently decided to support WYP activities in Europe by funding, at the 2M€ level, via the "Science and Society" programme, many European organisations under the leadership of EPS.

The main objective of WYP 2005 is to promote physics, to highlight its importance and impact in everyday life, and to remind us that physics is part of human culture. Its main target is the general public, and particularly young people. This will be exemplified in the 'kick-off' meeting of the International Year of Physics, "Physics for Tomorrow", which is being held at the UNESCO headquarters in Paris, from 13-15 January 2005. This conference, open to the general public, aims at capturing the attention of the international press and media, so that events and celebrations organised around the world throughout the year will attract public and media attention. Half of those attending the meeting will be young students (500, with age ~16-21) coming from all over the world, including developing countries from Africa and Asia. They will have the opportunity to closely interact with prestigious speakers (among them several Nobel laureates) who will present their views on the role of physics in society and in solving 21st century challenges (energy, environment, development...), on its trans-disciplinary character and its influence on other disciplines, on novel approaches to physics teaching and scientific education, etc.

As expected from an event that opens a year where increasing the public awareness of physics and physical sciences is a major goal, the 'kick-off' conference will exhibit marked features of general public interest. This must be the rule for all the events planned throughout the year 2005, and one expects every physicist to accept his responsibility in this respect during the coming year, being proactive in sharing his visions and convictions about physics and science with Society at large.

Happy and fruitful Year 2005!



Slippery Nanoworld

Enrico Gnecco[1], Anisoara Socoliuc[1], Ernst Meyer[1], Alexis Baratoff[1], Roland Bennewitz[2], Martin Dienwiebel[3] and Joost Frenken[4]

[1] National Center of Competence in Research "Nanoscale Science" and University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

[2] McGill University, Rutherford Physics Building, 3600 rue University, Montréal, Canada

[3] IAVF Antriebstechnik AG, Im Schlehert 32, 76187 Karlsruhe, Germany

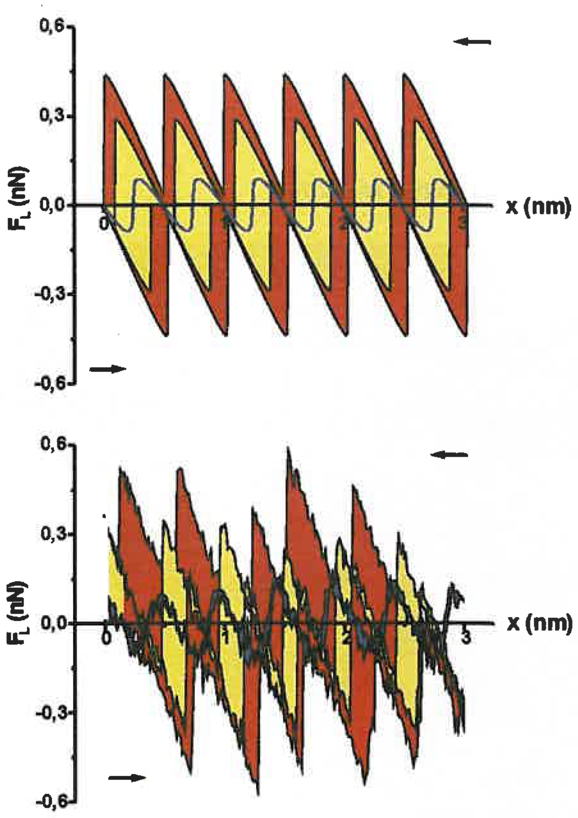
[4] Kamerlingh Onnes Laboratory, Leiden University, P.O. Box 904, 2300 RA Leiden, The Netherlands

Can two solid bodies slide past each other with negligible friction? Strictly speaking, zero friction would imply that no energy is dissipated in the sliding process. This means, for example, that sliding would not produce sound or thermal waves. The situation is reminiscent of the flow of a fluid without viscosity or of an electric current without resistance. However, one should be aware of the fact that superfluidity and superconductivity are quantum effects, whereas sliding with negligible friction can be explained on a completely classical basis. This phenomenon occurs if mechanical instabilities, which otherwise lead to energy dissipation, are suppressed while the bodies are still in contact. Even in that regime an extremely low *residual friction* must still be present. However, being not related to mechanical instabilities, this residual friction, due to the internal viscosity of the contact, is orders of magnitude lower than conventional dry friction, and to our knowledge falls below the detectability range of any instruments.

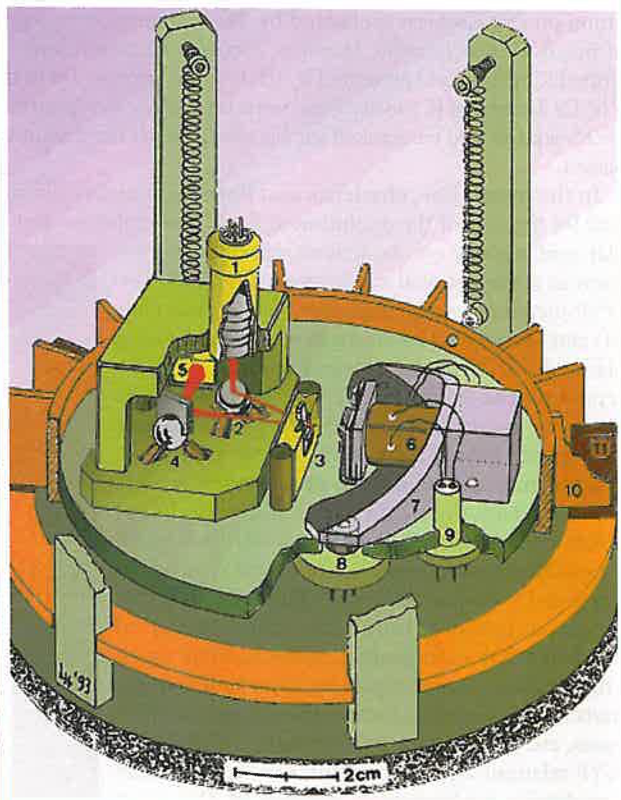
In this article we discuss recent experiments which clearly proved the achievement of negligible friction in different physical systems. Two different approaches were exploited to suppress mechanical instabilities. In the first case, negligible friction was observed after reducing the pressure between a sharp tip and a flat surface below a well-defined threshold. In the second case, the cancellation of friction resulted from an incommensurable contact formed between the sliding surfaces.

Transition from stick-slip to continuous sliding in atomic-scale friction

When two rough surfaces slide past each other, contacts are formed by a complex array of small asperities, which are continually connecting and disconnecting in the sliding process. For the sake of simplicity, we assume that one of the surfaces is perfectly flat and focus on the motion of a single asperity, thus avoiding all complications arising from interactions among asperities mediated by deformations of the sliding surfaces. The simplest model which describes that situation is a sharp tip connected to an external



▲ Fig. 1: (a) Simulated and (b) experimental lateral force acting on the AFM tip sliding back and forth on a salt crystal [2]. The dissipated energy given by the colored area decreases in a regular fashion when the applied load is reduced from 5.4 nN (red curve) to 4.0 nN (yellow curve) and suddenly vanishes after a further reduction to 0.2 nN (blue curve).



▲ Fig. 2: The atomic force microscope adopted to detect tiny lateral forces, home-built in Basel: (1) light source with optics; (2), (4) plane mirrors on spherical stepping motors; (3) cantilever holder with probing tip; (5) quadrant photodiode; (6) tube scanner with sample; (7) slider of two-dimensional stepping motor; (8) driving piezo; (9) fixed post; (10), (11) eddy current damping for spring suspension.

spring which is driven parallel to a surface (Tomlinson, 1929). The surface consists of an array of atoms ordered in a crystal lattice. We also suppose that the tip ends with a single atom, which is not an unrealistic assumption, judging from the resolution of atomic-scale features achieved in scanning tunneling and force microscopy. The effect of a larger contact area is discussed in the second part. Under usual conditions, if one tries to pull the spring, the tip remains close to a particular site on the surface until the lateral force becomes large enough to induce a *jump* into another equilibrium position. This mechanism called *atomic stick-slip* was first observed by Mathew Mate and coworkers in 1987 [1]. They observed that the positions at which a tungsten tip sliding on graphite sticks, are arranged like the atoms of the surface. Thus, the lattice structure of a surface can be revealed by mapping the lateral force on a tip at the end of a cantilever gently sliding over the surface.

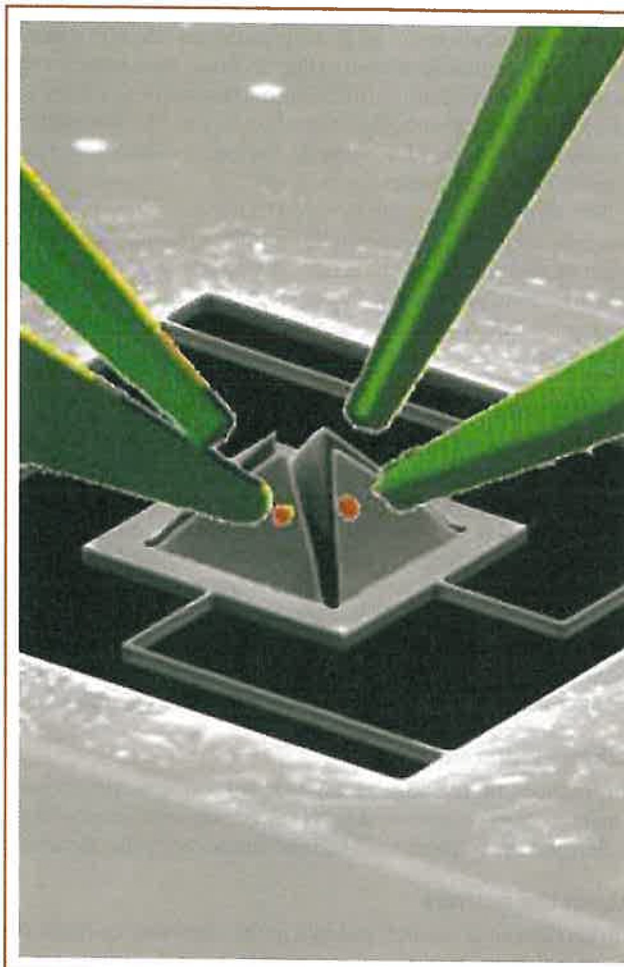
The atomic stick-slip motion is due to the combined action of the elastic force of the spring and of the periodically varying interaction between the tip and the surface. This motion can be recognised via the sawtooth pattern formed when the lateral force is plotted along the sliding path (Fig. 1a, red line). For further comparison with experimental results, the lateral force acquired while scanning backwards is also plotted. Energy is dissipated at each slip, where the position of the tip suddenly becomes unstable and the tip jumps releasing sound and thermal waves into the surrounding material. The total amount of dissipated energy is given by the area enclosed by the *friction loop* between forward and backward scans The shrill noise of a piece of chalk scratching over a blackboard is generated by the same mechanism, albeit on a much larger length scale. When the pressure on the chalk is reduced the intensity of sound decreases. A lower pressure on the tip corresponds to a lower interaction between tip and surface. The yellow line shows the lateral force expected in such a case. The curves corresponding to the forward and backward scans come closer, so that even though the jumps which reveal instabilities are still present, smaller disjoint friction loops appear and the dissipated energy is reduced. This implies that in each stick stage the equilibrium position of the tip now slightly moves when the spring is extended, due to decreased interaction with the surface. If the pressure on the tip is reduced below a certain threshold, it can be analytically proven that the tip should smoothly follow the spring (blue line). The instantaneous lateral force is not zero, but oscillates between positive and negative values giving rise to zero net dissipation, i.e. zero *friction*. This picture goes against our common perception of friction, in which the force always opposes the direction of motion. Indeed, the nanoworld behaves differently from the macroworld!

The definite experimental confirmation of this prediction of the Tomlinson model, has come only recently with a sharp hard silicon tip of an atomic force microscope (AFM) gently dragged over a salt crystal surface under dry conditions [2]. In the AFM, the lateral force between tip and surface can be estimated from the torsion of the cantilever that pulls the tip (Fig. 2). The torsion can be detected by a light beam reflected from the cantilever backside. The normal force or *load* between tip and surface is kept constant during the sliding by controlling the vertical deflection of the cantilever, which is also measured using the same light beam. The experiment was realised under ultra-high vacuum (UHV) conditions, in order to minimise the influence of contaminants. The exceptional signal to noise ratio of the instrument guaranteed the sensitivity required to observe the transition to the regime of negligible friction [3].

Fig. 1b shows three *friction loops* acquired while scanning back and forth a sodium chloride surface cleaved and cleaned in UHV by heating. The red curve represents the lateral force measured with a load of 5.4 nN. Each peak corresponds to the tip jumping from one atomic site to the next one. The area enclosed in the loop gives the energy dissipated while crossing six atomic sites. The yellow curve corresponds to a lower load of 4.0 nN. The lateral force acting on the tip exhibits split friction loops as in the simulation and the amount of dissipated energy is lower. A further reduction of the load to 0.2 nN has dramatic consequences (blue curve). The tip is now following the cantilever very smoothly, the lateral force is the same in both directions and the energy dissipation becomes negligible. The observed transition occurs while the tip is in contact with the surface. Indeed, a pulling force of 0.7 nN had to be applied to detach the tip. The quoted loads were estimated by adding this value to the force obtained from the vertical deflection of the cantilever.

Superlubricity of graphite

Frictionless sliding can also be achieved in a completely different way. When two atomically flat surfaces slide over each other, the



▲ Fig. 3: Tribolever™: dedicated friction force microscope, developed by the Leiden group for the investigation of superlubricity [5]. The figure contains a SEM image of the silicon force sensor. The tip is held in the central pyramid. Forces exerted on the tip lead to deformations of the four thin arms, that are detected by four laser interferometers, indicated by the tapered green fibers (not drawn to scale).

friction can be reduced to zero if (i) the surfaces are in contact over many atoms and (ii) their atomic lattices are incommensurate. This result is due to the fact the lateral forces between the atoms on the two non-fitting surfaces then sum up incoherently. Again, the (combined) lateral force does not reduce to zero but it varies periodically between modest positive and negative values, averaging out to a zero net friction force. In contrast with the previous example of zero friction, the load, pressing the two surfaces together, can be several orders of magnitude above the lateral forces at play inside the contact. This type of extreme friction lowering has been proposed under the name "superlubricity" [4]. Recently, superlubricity has been demonstrated experimentally in a dedicated instrument, the Tribolever (Fig. 3), which allows quantitative tracking of the forces on a scanning tip in three dimensions, with a resolution in lateral forces down to 15 pN [5]. With the Tribolever, a flake from a graphite surface was picked up and the lateral forces between flake and surface were measured at different relative angles of rotation [6]. Stick-slip motion and energy dissipation were clearly visible when the graphite lattices of the flake and the surface were aligned, which occurred at rotation angles of 0° and 60°. When the flake and the surface were rotated out of registry, to intermediate angles between 0° and 60°, the friction loops quickly reduced in amplitude, resulting in smooth sliding with negligible friction (Fig. 4). From the rotation angle needed for this reduction in friction, the area of the flake was inferred, in this case roughly 100 carbon atoms. This superlubricity was found to "survive" when the tip was pushed down with appreciable forces of several tens of nN.

The results on graphite have led to the speculation that the excellent lubricating properties of graphite powder may be the result of superlubricity, the motion between lubricated surfaces actually taking place between graphite flakes, most of which are misaligned with respect to each other, therefore sliding with ultra-low friction.

Applications

The observation of negligible friction is a promising result for the practical realisation of nanoelectromechanical systems (NEMS). Despite the increased ratio between surface and volume forces in these devices, an appropriate design of the sliding components should result in smooth motion with minimum energy consumption and without wear of the surfaces in contact. Our results suggest at least two possible ways to achieve this objective: (i) to work at exceptionally low loads and (ii) to exploit incommensurability between surfaces. It is conceivable that these mechanisms are also relevant in the complex mechanics of living organisms.

Acknowledgments

The authors are thankful Sergey Krylov for fruitful discussions. Their works were supported by the Swiss National Science Foundation and the Netherlands Organisation for Scientific Research.

About the authors

Enrico Gnecco is research assistant at the University of Basel. His research deals with friction force microscopy and development of "molecular machinery" within the Swiss NCCR "Nanoscale Science".
Anisoara Socoliuc is PhD student at the University of Basel. She mainly studied wear processes on the nanometer scale by friction force microscopy.
Roland Bennewitz has a "Canada Research Chair in Experimental Nanomechanics" at McGill University. His research activities focus on surfaces of insulating materials and mechanics on the nanometer scale.
Ernst Meyer is a Professor of Physics at the University of Basel. His research interests are the development of surface science techniques, such as friction force microscopy and dynamic force microscopy with true atomic resolution.
Alexis Baratoff is Professor of Physics at the University of Basel. His current activities focus on the interpretation and modelling of scanning probe microscopies and of molecular ordering on surfaces.
Martin Dienwiebel is now working in the research and tribology group at IAVF Antriebstechnik AG, Germany. His research interests focus on nanoscale wear and friction in lubricated systems.
Joost Frenken is a Professor of Physics at Leiden University, where he heads the Interface Physics Group. Central to his research are dynamic aspects of surfaces and interfaces.

References

[1] C.M. Mate, G.M. McClelland, R. Erlandson, and S. Chiang, Phys. Rev. Lett. 59 (1987) 1942

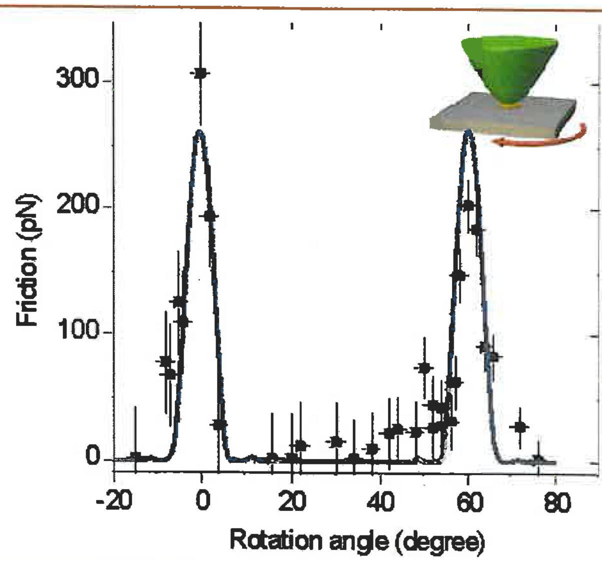
[2] A. Socoliuc, R. Bennewitz, E. Gnecco, E. Meyer, Phys. Rev. Lett. 92 (2004) 134301

[3] L. Howald, E. Meyer, R. Lüthi, H. Haefke, R. Overney, H. Rudin, and H.-J. Güntherodt, Appl. Phys. Lett. 63 (1993) 117

[4] M. Hirano and K. Shinjo, Phys. Rev. B 41 (1990) 11387

[5] T. Zijlstra, J.A. Heimberg, E. van der Drift, D. Glastra van Loon, M. Dienwiebel, L.E.M. de Groot, J.W.M. Frenken , Sensors and Actuators A: Physical 84 (2000) 18

[6] M. Dienwiebel, G. Verhoeven, N. Pradeep, J. Frenken, J. Heimberg, and H. Zandbergen, Phys. Rev. Lett. 92 (2004) 126101



▲ Fig. 4: Direct observation of superlubricity of graphite [6]. Each datapoint shows the energy dissipation per unit sliding distance, measured with the Tribolever between a tungsten tip and a graphite surface, for one orientation of the tip with respect to the graphite (see inset). These observations are explained by the presence of a graphite flake, picked up by the tip, which slides over the graphite surface. At 0° and 60° the lattices of the flake and the substrate match and friction is high. For intermediate angles, the friction is reduced to the detection level of the instrument. The curve is the result of a simple model calculation for a rigid, 96-atom graphite flake, sliding over a rigid graphite surface.

Drops that buckle

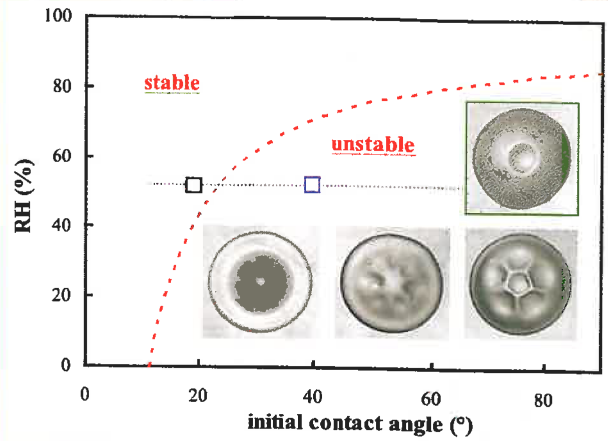
*Ludovic Pauchard, Jean-Pierre Hulin and Catherine Allain**
Laboratory FAST, Bât. 502, Campus Universitaire 91405 Orsay Cedex, France
**corresponding author: allain@fast.u-psud.fr*

The collapse of structures under the effect of their weight or other mechanical stress is of interest in many domains of mechanical and civil engineering [1]. Recently such phenomena have also been approached theoretically in the physics of instabilities dealing with shell and plate geometries [2]. When a structure, subjected to compression, displays large displacements transverse to the load, it is said to buckle [3]. A simple demonstration can be obtained by pressing the opposite edges of a flat sheet towards each other. This instability can be found in various systems, particularly when the volume enclosed within a thin and elastic envelope is made to decrease: collapse of concrete domes, vessels, etc. In general, for small volume variations the shape of the envelope remains the same (the flat sheet is kept plane). However for variations larger than a threshold value, deformations leading to variations of curvature can take place (the flat sheet bends). In this case, the inner volume can become very small with the outer surface displaying large wrinkles.

It has been recently shown that the buckling process is not only relevant to macroscopic systems that can be described through classical mechanics approaches. It is also important in a large variety of systems displaying a broad range of characteristic length scales: for example, amphiphilic or biological polymerized membranes or the buckling-driven delamination of metallic films, or morphology of certain leaves of plants, to name some.

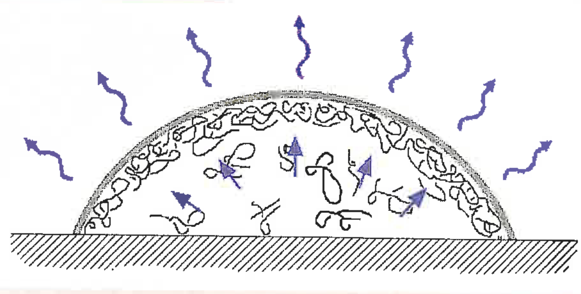
The present work deals with the drying of sessile drops (drops deposited upon a solid surface) of a polymer solution which is controlled by the diffusion of solvent vapour in air. The drying process first leads to the formation of a superficial rigid skin to be discussed below. In such systems, the buckling process results from complex spatial and temporal evolutions leading thus to various unexpected final shapes of the drops. For instance, the diagram in Figure 1 displays the top views of the drop shapes observed at the final stage of the drying process under different conditions (different initial contact angles of the drop onto the substrate and different relative humidity of the surroundings of the sessile drop).

The experiments were carried out using solutions of Dextran, a water-soluble polysaccharide, at high concentration $\omega_p = 0.40$g/g. At room temperature, the pure dry polymer is glassy and mechanically hard (its glass transition temperature is 220 ± 10°C). For a solution, the glass transition temperature ranges between that of the pure solvent and that of the pure polymer; it increases continuously with the polymer concentration. At a given intermediate temperature, there will be a concentration ω_{pg} such that the solution is fluid when $\omega_p < \omega_{pg}$ and glassy when $\omega_p > \omega_{pg}$. Also, during the drying process due to solvent removal, the polymer concentration increases with time and the solution, which is initially fluid, becomes glassy. The geometry considered here is that of a drop which is deposited onto a glass slide; the wetting properties of the substrates can be modified in order to vary the initial contact angle, θ_0. The setup is placed inside a glove box inside which the relative humidity, RH, is controlled. Following solvent



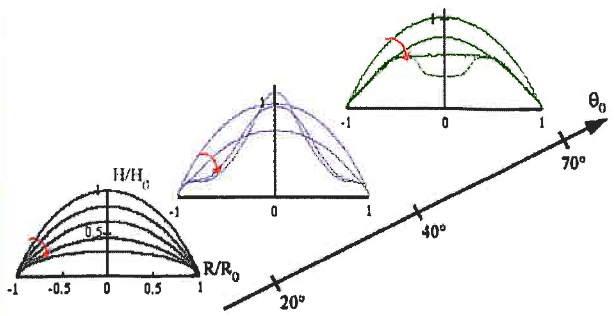
▲ Fig. 1: Diagram showing the instability occurrence for sessile drops during solvent loss under different conditions of initial contact angle (θ_0) and humidity rate (RH). The red dashed line (theoretical prediction) limits the "stable" and the "unstable" behaviour where drops get strong distortions during the drying process. Insets: images in top view taken at the final stage of the drying process; their location in the diagram corresponds to the conditions (θ_0, RH) necessary to form them. The diameter of the drop contact base is about 5mm.

removal, polymer deposition and adhesion onto the substrate leads to a strong pinning of the three-phase line [4, 5]: the drop evaporates with a constant contact area with the substrate, unlike a pure solvent drop which recedes with a constant contact angle. Inside the drop volume the polymer concentration is not uniform with time but becomes higher near the outer surface where evaporation takes place (Figure 2). So, when the polymer concentration reaches ω_{pg} in this region, a glassy skin forms. This skin is too thin to change significantly the evaporation rate (diffusion continues through the thickness of the skin). Then the drop surface is rigid whereas the inner volume decreases due to evaporation: a buckling process can therefore take place. Note that, for the instability to occur, it is necessary that the core of the drop be still fluid when the glassy skin forms at the drop surface. By studying the variations with time of the profiles, volume and surface area of the drops, we have confirmed that the instability occurring in the experiments is indeed a buckling instability. By comparing the characteristic drying time and the time required to form a glassy skin at the drop surface, it is possible to obtain a criterion for the observation of the instability (red dashed line in the diagram of Figure 1) [6].



▲ Fig. 2: Schematic illustration of the build up of a glassy "skin" at the drop surface due to the accumulation of the polymer chains near this region.

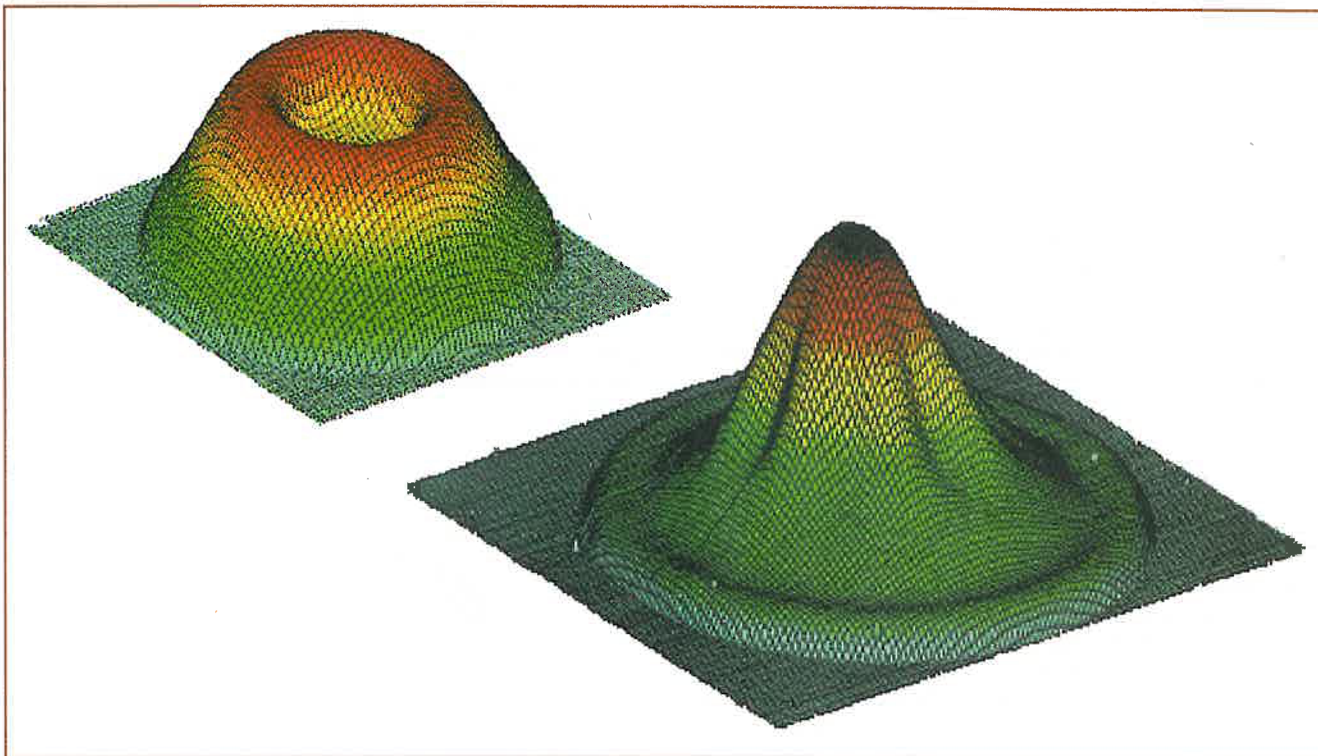
features



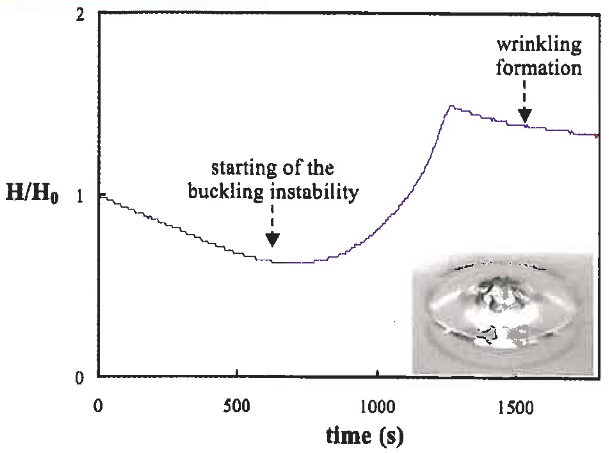
▲ **Fig. 3:** Superposition of dimensionless profiles of sessile drops of dextran solutions recorded at different times during desiccation (RH=50%). The time elapsed between two consecutive profiles is 300s. The characteristics of each drops are (H_0 denotes the initial drop height and R_0 the initial basal radius of the drop) : (a: grey) H_0=0.8mm, R_0=2.8mm, θ_0=20°; (b: blue) H_0=1.8mm, R_0=3.5mm, θ_0=40°; (c: green) H_0=1.9mm, R_0=2.6mm, θ_0=70°. Here each drop remains axisymmetric.

Let us now analyse the distortions of the drop shapes when the initial contact angle is varied at fixed relative humidity (horizontal grey dashed line of Figure 1 - RH = 50%). For low contact angles (θ_0 < 20°), the drop progressively flattens following solvent evaporation. The shape of the drop is not strongly modified, as shown by the superposition of profiles recorded at different time on Figure 3a (conditions corresponding to the grey left square in the diagram in Figure 1). The region of the diagram in Figure 1 where this behaviour can be observed is named "stable"; in the other regions large distortions of the sessile drops are observed ("unstable behaviour"). For higher contact angles (20° < θ_0 < 60°), the drop flattens in a stage and the height of the apex decreases at first but starts to increase again after a certain time (see superposition of profiles in Figure 3b corresponding to the blue right square in the diagram in Figure 1). For still higher contact angles (θ_0 > 60°), the drop flattens as the apex height progressively decreases following the same trend as in the previous cases. Then the top of the drop decreases at a faster rate and a depression forms leading to an inversion of the curvature (Figure 3c and the right top inset in Figure 1 surrounded with a green line)[6]. Such a curvature inversion has also been observed in the mechanics of a "ping-pong" ball i.e. in the compression of an elastic spherical shell [7]. At the final stage of the drying the drop shape displays a circular fold, with a dip at the centre of the droplet, only observable on profilometry measurements (Figure 4a) [8].

Let us now consider again the influence of the initial contact angle on the distorted shape of the drop but this time at a lower relative humidity (RH = 30%). This time, the rate of evaporation is higher. As a consequence, the polymers rapidly accumulate at the drop surface (the concentration gradient having less time to relax) and the glassy skin forms earlier in the course of the drying than at a higher relative humidity [6]. Thus the buckling process takes place for a smaller contact angle (see Figure 1). Moreover, for initial contact angle such as 20° < θ_0, the large volume variation that will take place after skin formation results in secondary instabilities such as wrinkling, breaking the axisymmetry of the distorted drops. For 20° < θ_0 < 60°, at first the drop flattens and the height of the drop decreases as shown in dimensionless coordinates in Figure 5. Then the apex height quickly increases and reaches a maximum value (peak formation). After a few minutes secondary instabilities take place and break the axisymmetry of the drop: radial wrinkles appear all around the peak (see Figure 4b and inset in Figures 1 and 5). For higher initial contact angle (θ_0 > 60°), the curvature at the top of the drop changes sign during the drying process as already observed for RH = 50%. Then a



▲ **Fig. 4:** 3D maps of the drop corresponding to (a) RH=50%; θ_0=70°; R0=2.6mm and (b) RH=30%; θ_0=40°; R0=2.9mm. These profiles were measured using a mechanical profilometer (length scales are amplified in the *z* direction to improve legibility).



▲ Fig. 5: Time variations of the apex height in dimensionless coordinates for a sessile drop measured during solvent loss at low humidity rate (RH=30%; θ_0=40°; R_0=3.1 mm). After the primary buckling instability leading to an axisymmetric "peak", a secondary instability takes place and breaks the axisymmetry of the drop. Inset: image taken at 45° of such drop at the final stage of the drying process: radial wrinkles are clearly observable all around the peak formed by the first buckling instability (also in Figure 4b).

cascade of buckling events takes place, resulting in a complex pattern. At the final stage the top view of the drop is shown in the corresponding inset in Figure 1.

A sessile drop which dries would at first appear as a simple problem. However our experiments reveal that a combination of several processes take place during the drying process and that, depending on the experimental conditions, different morphologies can be observed at the drying end. These are strongly related to the different modes of the buckling instability which take place in an elastic shell. This leads to various shapes that exhibit axisymmetric or non-axisymmetric distortions. These phenomena are also related to a large variety of industrial applications including the formation of coatings. Such investigations may also help to solve a variety of problems in film, membrane or bio-interface mechanics.

References

This article is based on an original version published in the "Bulletin de la SFP" (French Physical Society), 140, p.4, Jul. 2003.

[1] W. Flugge, Handbook of Engineering Mechanics; New York, McGraw-Hill (1962).

[2] J. W. Hutchinson, J. Appl. Mech., 8, 49 (1967).

[3] S. Timoshenko and J. M. Gere, in Theory of Elastic Stability; 2nd ed. New York, McGraw-Hill (1961).

[4] F. Parisse and C. Allain, J. Phys. II, 6, 1111 (1996).

[5] R. D. Deegan, O. Bakajin, T. F. Dupont, G. Huber, S. R. Nagel and T. Witten, Nature, 389, 827 (1997).

[6] L. Pauchard and C. Allain Europhys. Lett., 62 (6), pp. 897-903 (2003) ; Y. Gorand, L. Pauchard, G. Callegari, J. P. Hulin, C. Allain Langmuir 20(12) pp. 5138-5140 (2004).

[7] L. Pauchard, S. Rica Phil. Mag. B, 78 (1998).

[8] J. M. Boffa, C. Allain and J. P. Hulin, Eur. Phys. J., AP 2 281 (1998).

Ternary and quaternary fission

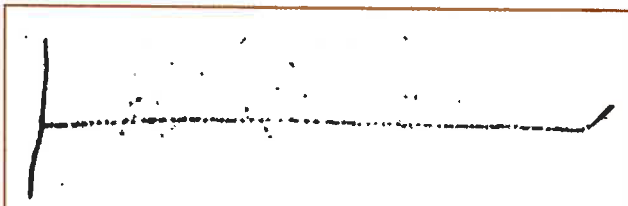
Friedrich Gönnenwein [1], Manfred Mutterer [2] and Yuri Kopatch [3]
[1] Physikalisches Institut, Universität Tübingen, Germany
[2] Institut für Kernphysik, Technische Universität Darmstadt, Germany
[3] Frank Laboratory of Neutron Physics, JINR, Dubna, Russia

Nuclear fission has become known in the late thirties of the last century as a process where a heavy nucleus such as Uranium or Thorium decays into two fragments of about the same mass. The process was discovered while irradiating natural Uranium with thermal neutrons [1] and it soon became evident that among the U-isotopes it was ^{235}U to be held responsible for the reaction ^{235}U(nth,f) observed. Shortly afterwards it was found that heavy nuclei such as ^{238}U may also undergo fission spontaneously [2].

Whether by spontaneous or induced fission, the mother nucleus disintegrates in the overwhelming fraction of cases just into two fragments. Fragmentation into three or more daughter nuclei of about equal mass has up to the present not been detected unambiguously. There is a full range of some 800 different fragment nuclei formed with as a rule the fragment being very neutron rich. A peculiarity of low energy fission is the asymmetry of the mass division: in the lighter actinides from Thorium to Einsteinium, the nuclei disintegrate asymmetrically in the sense that predominantly a heavier and a lighter fragment is produced. For example, in a fissioning nucleus such as ^{236}U, a typical ratio of heavy/light fragment mass numbers is 140/96.

Ternary fission

Sometimes instead of the standard "binary fission" a ternary process with three charged particles in the outgoing channel is observed, but with the third particle being very light compared to the fission fragments proper. This "ternary fission" process was discovered by several groups in the '40s of the last century. The technique was to soak photographic emulsions with Uranium salts and to irradiate the emulsion with thermal neutrons. Ionising particles leave tracks that after development of the emulsion may be visualised under a microscope. An example is provided in Figure 1 [3]. The two heavily ionising tracks starting at the vertex of the three-pronged event (in the figure upward and downward)



▲ Fig. 1: Ternary fission event observed in a photographic nuclear emulsion. From the vertex one fragment is moving upwards and the complementary fragment is moving downwards. The track to the right side is due to a long range α-particle. Reaction: ^{nat}U(n,f), from Ref. [3].

belong to the two main fission fragments. A third less ionising track is observed at roughly 90° to the axis formed by the fragments. From its ionisation density it was concluded that it must be an α-particle, i.e. the He-isotope ^4He. The first conjecture then was that it could be an α-particle from the radioactive decay of Uranium? But an α-particle from the radioactive decay of one of the isotopes of natural Uranium would have a kinetic energy not exceeding 5 MeV and its track length in emulsions should be comparable to the track length of the fission fragments. Therefore the "long range α" seen in Figure 1 is definitely not due to radioactive decay. Instead, these α-particles must be formed in the process of fission.

The first question to be answered concerns the probability of ternary fission compared to binary fission. The systematic study of ternary fission with electronic detectors for fragments and light charged particles in coincidence revealed that the ratio t / b of the ternary to binary yield never exceeds a few tenths of a percent in low energy fission. Thus, ternary fission is indeed a very rare process. Another remarkable feature is that the yield ratio e.g. in thermal neutron induced fission stays close to $t / b \approx 2 \cdot 10^{-3}$ for reactions ranging from $^{229}Th(n_{th},f)$ up to $^{251}Cf(n_{th},f)$. In spontaneous fission the t / b ratios are slightly larger [4, 5]. In the following we will focus on these reactions where sources with large fission rates are available.

Where and when are ternary particles born ?

Next, one would like to know where and when the ternary particles are getting shape. Information on this question has come from the analysis of α-particle energies and of angular correlations between these particles and the fission fragments. A comprehensive overview of α–particle energies and emission angles is on display in Figure 2 for spontaneous fission of ^{252}Cf [5]. In the polar diagram each point corresponds to an α-particle event. The distance of the point from the centre characterises the kinetic energy and the polar angle Θ indicates the angle between the α-particle and the lighter of the two fragments. The lighter fragment flies in the figure at the polar angle $\Theta = 0°$ to the left. Evidently the α-particles have a broad energy distribution with energies up to 30 MeV. As to the angular distributions, the majority of α-particles comes off roughly at right angles to the fission fragments. Both features could already be guessed from the observation of single events such as that shown in Figure 1. It is obvious from Figure 2 that the angular distribution is not perfectly symmetric relative to the polar angle 90°. Instead, the distribution is shifted towards polar angles smaller than 90°, i.e. in direction of the lighter fragment.

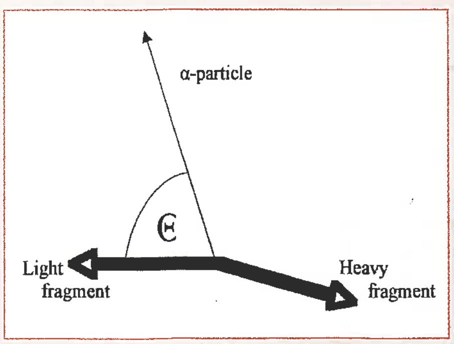
Intuitively the characteristics of the angular distributions point to an emission of α-particles from a region between the two nascent fragments. This can be seen from the following arguments. Since upon scission of a dividing nucleus a short lived neck joining the two fragments is formed, it is tempting to conjecture that α-particles are formed while the neck is rupturing. Ternary particles are in this view remnants of the neck. Stated in other words, binary fission should correspond to a single rupture of the neck filament, while in ternary fission the neck is cut at two places before the stubs of the neck can recede and be absorbed by the fragments. Thus a third particle is set free [6]. The combined Coulomb forces from the two heavier fragments acting on the light charged particle will then accelerate this particle and push it out of the neck region at roughly right angles to the fission axis, or more precisely, as observed in experiment (cf. Fig. 2), at an angle slightly shifted towards the light fragment. This is attributed to the fact that the push exerted by the heavier fragment carrying a higher nuclear charge is larger than the one due to the light fragment. The above simple picture has been substantiated by trajectory calculations of several authors where essentially the Coulomb forces between the three bodies come into play

A more delicate question is at what stage of the fission process is the decision taken to emit an α-particle. Is the formation of an α-particle already settled at a very early stage of fission when the fission-prone nucleus just starts to deform? Or does the α-particle come into view at the saddle point of deformation, *i.e.* at the fission barrier, when the nucleus is bound to continue on its way to scission? Or does the α-particle only takes shape at the very last stage of scission? A key to answer this question has been found while investigating the angular distributions of fission fragments and comparing the anisotropies observed in binary and ternary fission. According to theory the angular distributions of fragments are determined by the wave functions describing the transition states of the saddle point. The remarkable result for all reactions analysed is that the angular distributions of fission fragments are identical in binary and ternary fission. Hence, at the saddle point, there is no trace whatsoever of ternary particles. The light particles must be born in the last stage of the process near or right at scission during neck rupture [7]. There are good reasons to believe that neck rupture is a process quite similar to the instabilities of a filament of water analysed by Lord Rayleigh at the end of the nineteenth century. Fluctuations in the microscopic motion of nucleons in the neck should introduce an element of randomness and both the location of the cut and the number of cuts are expected to exhibit fluctuations that lead either to binary or ternary fission.

Ternary fission

In standard nuclear fission the mother nucleus disintegrates in a binary decay into two fragments of comparable mass. Very rarely a light charged particle accompanies the main fragments. In most cases the third particle of ternary fission is an α-particle. The light particles are born together with the main fragments when the nucleus breaks apart at scission. From the angular distributions of these α-particles relative to the fragments it is concluded that they are formed in the neck region between the two separating fragments. The Coulomb force will then expel the light particle roughly at right angles to fragment motion as observed experimentally (cf. Figs. 1 and 2). By contrast, fission neutrons are evaporated from the fragments well after scission when the fragments have been fully accelerated by the Coulomb interaction.

In the drawing the lighter of the two main fragments is flying to the left. The emission angle Θ of the ternary α-particle is measured by convention relative to the direction of flight of the lighter fragment. Most α-particles are focused into a cone at about right angles relative to fragment motion. Note that, due to momentum conservation, in ternary fission the strict collinearity of the two fragments is lost.



Ternary particles other than α-particles

So far only α-particles were addressed as the light ternary particles. Though α-particles contribute ~90% and hence the lions share to the total ternary yield, there are many other light ions which become observable as ternary particles [4,5]. The most important ones to be mentioned are the hydrogen isotopes, viz. protons, deuterons and tritons. They carry ~1%, ~0.5% and ~6% of the total yield, respectively, the neutron-rich triton being the most abundant hydrogen isotope amongst the ternary particles. Neutron-rich isotopes also dominate the yield of other elements. For example, the isotope ^{3}He has so far completely escaped detection. By contrast, in the heavier elements the neutron-rich isotopes, ^{6}He, ^{8}He, ^{9}Li, ^{10}Be, ^{13}B and ^{14}C for example, have sizable yields [5].

The favoured production of neutron-rich isotopes has led to the conjecture that possibly neutrons could also be ejected at scission. However, there is only indirect evidence for their existence. In experiments aiming at a direct detection no scission neutrons were seen.

The heaviest ternary particles observed

One may wonder which are the heaviest nuclei to be detected and identified as ternary particles. Experiments are difficult due to the fact that besides ternary fission being a rare process, the yield for nuclei heavier than ^{4}He is only some 3% of the total ternary yield. In the search for the heaviest ternary particles the electromagnetic mass separator "Lohengrin" installed at the High Flux Reactor of the Laue-Langevin Institut in Grenoble/France has proven to be an ideally suited instrument. The ion source of Lohengrin is just a thin layer of fissile material irradiated by neutrons from the reactor. Any charged ions such as fission fragments or charged ternary particles emitted by the source and intercepted by the spectrometer will be analysed according to their mass and energy. With a standard ? Δ-E_{rest} detector installed in the focal plane of the spectrometer the nuclear charges of the ions are also assessed. Systematic studies have been conducted for thermal neutron-induced reactions on target nuclei ranging from ^{233}U up to ^{249}Cf. Results for the two reactions ^{235}U(n_{th},f) and ^{249}Cf(n_{th},f) are on display in Figure 3 [8]. The yields of ternary particles per 100 fission reactions are given in the left part of the figure. For the ^{235}U target the heaviest ternary particle to be observed at the limit of detection of the instrument was ^{22}O, while for the ^{249}Cf target the heaviest isotopes were ^{37}Si and ^{37}S. Yields down to $3 \cdot 10^{-9}$ per fission event could be measured. The yield curves are not levelling off and, hence, heavier ternary particles with still lower yields are expected to be produced.

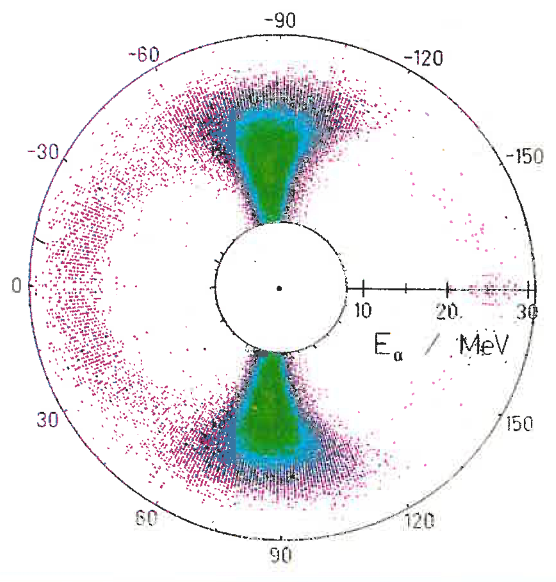
One may ask why at the same level of yields in Figure 3 the masses of ternary particles increase with the mass of the mother nucleus when comparing the two reactions ^{235}U(n_{th},f) and ^{249}Cf(n_{th},f). An answer may be found by inspecting the fragment mass distributions. These are shown in the right part of Figure 3. The binary fragment mass distributions conspicuously exhibit the asymmetric split of the mother nucleus, leading to a heavy and a light fragment group. It is worthwhile to point out that the fragment yields for the two reactions under study coincide at mass numbers around $A \approx 132$ in the heavy mass group and around $A \approx 76$ in the light mass group. The mass $A = 132$ is singled out due to the extra-stability of the 132Sn nucleus with a magic $Z = 50$ proton cluster and a magic $N = 82$ neutron cluster. The shell-stabilisation of ^{132}Sn (and some neighbouring nuclei) is, in fact, understood to be one of the roots for the preference of asymmetric mass splits in the actinides. Similarly, in the light mass group one may anticipate the influence of the magic proton cluster $Z = 28$ (Ni) and the magic neutron cluster $N = 50$. Though the doubly magic nucleus ^{78}Ni could not be detected in low energy fission, nevertheless, the cooperation of the two magic clusters is thought to be responsible for the enhancement of yields in the mass number window $A = 70$ to $A = 80$, a phenomenon having been called "super-asymmetric" fission.

What can now be learned from asymmetric and super-asymmetric fission for the yields in ternary fission? Again a simple picture might be helpful. Let us assume that for the reactions under study in the heavy fragment there is an $A = 132$ core and in the light fragment an, say, $A = 76$ core which both strongly resist being broken up. This would then leave for the number of neck nucleons in fission of ^{236}U*: $[236 - (132+76)] = 28$ nucleons and in fission of ^{250}Cf*: $[250 - (132 + 76)] = 42$ nucleons. The increase in available number of neck nucleons in Cf compared to U therefore explains the increase in yield of heavy ternary particles for increasing mass numbers of the mother nucleus.

As seen in the figure there is still a gap in mass number between the heaviest ternary particles and the lightest fission fragments. In the cluster picture outlined for the scission configurations this is indeed not surprising. However, the probability of breaking up the cluster cores, although small, is strictly speaking not zero. Therefore, one should expect non-zero yields also in the gap region of masses in Figure 3, albeit at yield levels that are presently inaccessible. Interestingly, as the excitation energy of the fissioning nucleus is raised, the gap is rapidly filled and the ternary and binary yield distributions are smoothly joined.

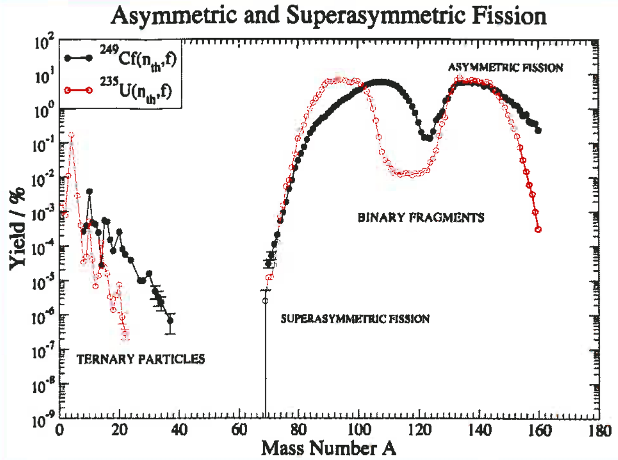
Mass distributions of fragments in ternary fission

We stress once more that the mass distributions on display in Figure 3 are for fragments from binary fission. In ternary fission these fragment mass distributions will certainly be different. The



▲ Fig. 2: Scatter plot of ternary α-particle emission from ^{252}Cf(sf). In the polar diagram the fissioning nucleus is located at the centre with the light fragment moving to the left ($\Theta = 0°$) and the heavy fragment to the right ($\Theta \approx 180°$). Each point in the plot corresponds to an α-particle from ternary fission. Energies of the ?-particles are represented as radii measured from the centre. Their angles of emission relative to light fragment momentum are given as the polar angles Θ of the radius vector, from ref. [5].

features



▲ Fig. 3: On the right side are depicted the mass yields from binary fission of $^{249}Cf(n_{th},f)$ and $^{235}U(n_{th},f)$ as black and red circles, respectively. On the left side are shown the mass yields of ternary particles from the same two reactions, from ref. [7].

differences will be the more pronounced the heavier the ternary particles are, since more and more nucleons are missing for the formation of fragments. Results for the spontaneous fission reaction $^{252}Cf(sf)$ are presented in the following. In experiment, besides the two main fragments, the ternary particle energies, masses and charges were measured in coincidence [8, 9]. The fragment mass distributions in ternary fission are shown in Figure 4 for ^4He and for Be isotopes as the ternary particles. Data points are for fragments from ternary fission while the dashed red lines trace the distributions from binary fission for comparison. The binary and ternary yields have been normalised to the same number of events. It must be pointed out, however, that for experimental reasons the ternary mass distributions pertain to ternary particle energies in excess of 8 MeV and 26 MeV for ^4He and the Be-isotopes, respectively. It is obvious from the figure that in going from binary to ternary fission the mass distributions are not displaced as a whole but are getting narrower the heavier the ternary particle is. Most remarkably the mass number of the lightest fragment in both the heavy and the light mass group appears to stay constant while the heaviest fragment in both groups is shifted downward to smaller masses. It should be noted that the lightest fragment in the light group is complementary to the heaviest fragment in the heavy group (asymmetric fission) and vice versa for the lightest fragment in the heavy group and the heaviest fragment in the light group (near symmetric fission). In order to compensate for the loss in nucleon numbers going into the ternary particles, at fixed mass numbers of the lightest fragments the fragment mass distributions have to become narrower the heavier the ternary particle is.

It is tempting to attribute the characteristic changes in the mass distributions once more to the cluster structure of fragments. It again appears that both in the light and the heavy fragment the shell-stabilised clusters discussed in connection with Figure 3 are resistant to break-up. These clusters fix the locations of the foothills to the left of the two humps for both, light and heavy fragments. In the heavy group the stabilisation of mass numbers around mass A = 132, with the key nucleus being ^{132}Sn, is readily recognised. For the light group we have to recall that the stabilising effect for mass numbers around A = 76 sets in at very low fission yields, in fact too low to become detectable in the rare ternary decay (cf. Fig. 3).

Neutron emission in ternary fission

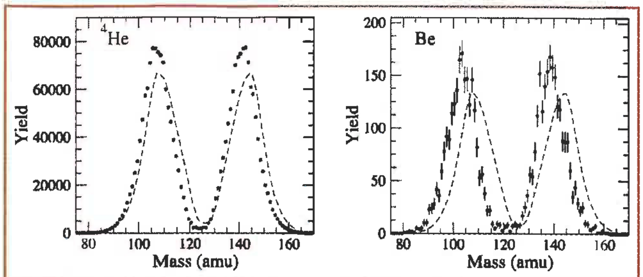
The study of neutron emission from fragments in ternary fission gives additional support to the role played by nuclear shell structure in the process. In the experiment on $^{252}Cf(sf)$ already quoted [9], the chamber where the charged particles were registered was placed at the centre of the Heidelberg crystal ball [10]. The ball with its 162 NaI(Tl) crystals is primarily a γ-detector but also allows neutrons to be detected. Thus neutron emission from fragments in ternary reactions could be studied for different types of ternary particles. A sample of results is displayed in Figure 5 [9] where, for the same ternary reactions with ^4He and Be-isotopes accompanying fission shown in Figure 4, the neutron multiplicity numbers $<\nu(A)>$ as a function of fragment mass A are plotted. Data from ternary fission are shown as black circles with error bars. The neutron multiplicities from binary fission are sketched for comparison as dashed red curves.

For discussion it should be noted that neutrons (and to a lesser extent also γ-quanta) carry away the excitation energy of fragments. At scission, however, the main part of the excitation energy of the eventual fragments is still tied up as deformation energy. After scission the deformation will relax and the energy liberated will be found back in the intrinsic energy of the fragments. The neutron multiplicity thus carries information on the deformation of fragments at scission. With this correspondence in mind the sawtooth-like shape of the neutron multiplicity $<\nu(A)>$ in Figure 5 is an intriguing feature of nuclear fission. Striking to eye is the virtual disappearance of neutron multiplicity near mass A = 132. A similar vanishing multiplicity is also observed for masses near A = 80 which is, however, not shown in Figure 5. This says that the cluster-like fragments, having been repeatedly referred to as being extra-stable, are also extra-stiff and survive the elongation process of fission without being appreciably deformed themselves. By contrast, the complementary fragments emitting many neutrons were strongly deformed at scission. In fact, in binary fission of $^{252}Cf(sf)$ the peak in the neutron distribution is found at mass A = 120, *i.e.* exactly complementary to the heavy cluster with mass A = 132.

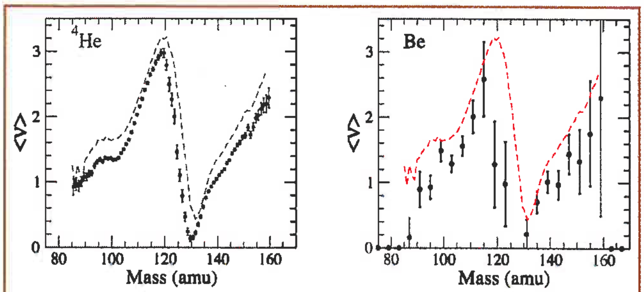
As is evident from the figure, the neutron multiplicities in ternary fission are generally lower than in binary fission. For example, in $^{252}Cf(sf)$ the multiplicity $<<\nu>>$ averaged over all mass splits is 3.77 in binary and 3.07 in α-accompanied fission [11]. In ternary fission with Be as the ternary particle the neutron multiplicity drops even lower to about 2.6 [9]. The decrease in neutron number implies that some of the fragment excitation energy, which at scission is stored as deformation, is consumed by ternary particle emission. A still more detailed insight is obtained from inspecting the mass-dependent neutron multiplicity $<\nu(A)>$. In particular Figure 5 shows that for Be accompanied fission the multiplicity peak observed in binary fission at A = 120 has shifted downward towards smaller mass numbers of the light fragment. Since among the ternary Be yields the isotope ^{10}Be by far dominates the yield, in fission accompanied by the emission of Be-isotopes the light fragment mass A = 110 is complementary to the heavy fragment mass A = 132. As seen in Figure 5, in experiment the multiplicity peak in the light fragment comes indeed close to A ≈ 110. This appears to indicate that also in ternary fission a maximum of deformation is accumulated in fragments complementary to the cluster fragments.

Unstable ternary particles and quaternary fission

Although the main lines of ternary fission have now been traced there are many more interesting facets of this process to be disclosed.



▲ Fig. 4: Fragment mass distributions in ternary fission of ^{252}Cf(sf) with ^{4}He and Be as the light charged particles (black points with error bars in the left and right panel, respectively). Yields are given as the number of events measured. Binary mass distributions are shown for comparison as red dashed curves. For each reaction the binary distributions are normalised to the total number of counts in the ternary distribution, from ref. [8].



▲ Fig. 5: Neutron multiplicities as a function of fragment mass in ternary fission of ^{252}Cf(sf) with ^{4}He and Be as the light charged particles (black points with error bars in the left and right panel, respectively). Neutron multiplicity data from the corresponding binary fission reaction are given as dashed red curves, from ref. [8].

In particular the measurement of particle-unstable ternary particles has been of importance because in some cases the decay products may contribute to the yields of lighter ternary particles. Prominent examples of unstable ternary particles are the He-isotopes ^{5}He and ^{7}He. They decay by neutron emission with lifetimes of $1.1 \cdot 10^{-21}$s and $4.1 \cdot 10^{-21}$s, respectively, and therefore well before being intercepted in charged particle detectors. Their yields in ^{252}Cf(sf) could be determined in recent experiments by exploring the angular correlations between neutrons and the ternary particles[12]. A remarkable result is the large percentage of ^{4}He and ^{6}He observed in charged particle detectors which in reality are the remnants of ^{5}He and ^{7}He following n-decay. The yield ratios ^{5}He / ^{4}He and ^{7}He / ^{6}He are both equal to 0.21(5). This means that only about 83 percent of the α-particles measured are in reality primary α-particles while about 17% have originally been created as ^{5}He nuclei. Behind ^{4}He, the second most important ternary particle is the He-isotope ^{5}He, and not the H-isotope ^{3}H as was held to be true in the past.

Besides ternary isotopes being unstable to n-decay, charged particle decay has also to be taken into account. A prominent example is ^{8}Be with a lifetime of $6.7 \cdot 10^{-17}$s for the ground-state decay $^8\text{Be} \rightarrow (\alpha + \alpha)$. This decay is intriguing because the $(\alpha + \alpha)$ events observed could also be due to a simultaneous emission of two light charged particles in a single fission decay. In contrast to ternary fission with only one charged light particle the above processes are called quaternary fission. The way to disentangle true quaternary $(\alpha + \alpha)$ events from the sequential decay of ^{8}Be into $(\alpha + \alpha)$ is by analysing the angular correlations between the two α-particles. Studies of quaternary fission have been performed for spontaneous and thermal neutron-induced reactions. For the ^{252}Cf(sf) reaction it is found that the yield for simultaneous $(\alpha + \alpha)$ emission is about 10^{-6} per fission while the production of ^{8}Be is about three times more probable. In the reactions $U(n_{th},f)$ with either the ^{233}U or ^{235}U isotope as target these yields are down by roughly an order of magnitude [13].

Gamma emission in ternary fission

Let us close the present survey of ternary fission phenomena with a remark on γ-emission in fission. Gamma-rays carry away the fragment excitation energy left behind after neutron evaporation. In addition, they bear information on the angular momentum the fragments acquire near scission. Remarkably, it is found that the spins are oriented at right angles to the fission axis. Models are explaining this orientation of fragment spins by a butterfly-like oscillation of the two deformed fragments facing each other at scission but still sticking together [14]. These rotary oscillations impart spin to the fragments which is indeed pointing at right angles to the fission axis. Spin orientation leads to anisotropic γ-emission relative to the fission axis. As regards ternary fission one should expect that in a strongly excited butterfly mode the ternary particles are released in the direction of motion of the two fragment tips in the rotary oscillation. However, no indication of correlated gamma-ternary particle emission has been found in experiment [15]. This particular result adds to the more general difficulties in understanding the generation of angular momentum in fission fragments.

Finally, let us stress that beyond this specific problem of angular momentum, ternary fission continues to be not merely a curious peripheral-aspect of fission but, as shown in the present survey, is a precious source of information on the complex, and in many respects still puzzling, fission process as a whole.

References

[1] O. Hahn and F. Strassmann, Naturwissenschaften 27, 89 (1939)

[2] K. A. Petrzhak and G. N. Flerov, J. Phys., USSR 3, 275 (1940)

[3] Tsien San-Tsiang et al., Phys. Rev.71, 382 (1947)

[4] C. Wagemans in The Nuclear Fission Process (CRC Press, ed. C. Wagemans, 1991),

[5] M. Mutterer and J. P. Theobald in Nuclear Decay Modes (IOP Press, ed. D. N. Poenaru, 1996)

[6] V. A. Rubchenya, Sov. J. Nucl. Phys. 35,334 (1982)

[7] F. Gönnenwein, Proc. Conf. Nuclear Data for Science and Technology, Santa Fe, USA, 2004, tobe published

[8] F. Gönnenwein, Nucl. Phys. A 734, 213 (2004)

[9] M. Mutterer et al., to be published

[10] P. Singer et al., Zeitschr. f. Phys. A 359 41 (1997) and PHD thesis, TU Darmstadt 1997

[11] G. K. Mehta, et al., Phys. Rev. C7, 373 (1973)

[12] Yu. N. Kopatch et al., Phys. Rev. C 65, 044614 (2002)

[13] P. Jesinger et al., to be published

[14] J. O. Rasmussen et al., Nucl. Phys. A 136 465 (1969)

[15] Yu. N. Kopatch et al., Phys. Rev. Lett. 82, 303 (1999)

features

Quantum computers: where do we stand?

Giuliano Benenti[1,] and Giulio Casati[1,2,†]*
[1] Center for Nonlinear and Complex Systems, Università degli Studi dell'Insubria and Istituto Nazionale per la Fisica della Materia, Unità di Como, Via Valleggio 11, 22100 Como Italy
[2] Istituto Nazionale di Fisica Nucleare, Sezione di Milano, Via Celoria 13, 20133 Milano, Italy

Quantum mechanics has had an enormous technological and societal impact. To grasp this point, it is sufficient to cite the invention of the transistor, perhaps the most remarkable among the countless other applications of quantum mechanics. It is also easy to see the enormous impact of computers on everyday life. The importance of computers is such that it is appropriate to say that we are now living in the information age. This information revolution became possible thanks to the invention of the transistor, that is, thanks to the synergy between computer science and quantum physics. Today this synergy offers completely new opportunities and promises exciting advances in both fundamental science and technological application. We are referring here to the fact that quantum mechanics can be used to process and transmit information [1,2].

Miniaturization provides us with an intuitive way of understanding why, in the near future, quantum laws will become important for computation. The electronics industry for computers grows hand-in-hand with the decrease in size of integrated circuits. This miniaturization is necessary to increase computational power, that is, the number of floating-point operations per second (flops) a computer can perform. In the 1950's, electronic computers based on vacuum-tube technology were capable of performing approximately 10^3 floating-point operations per second, while nowadays there exist supercomputers whose power is greater than 10 teraflops (10^{13} flops). As we have remarked, this enormous growth of computational power has been made possible owing to progress in miniaturization, which may be quantified empirically in Moore's law. This law is the result of a remarkable observation made by Gordon Moore in 1965: the number of transistors on a single integrated-circuit chip doubles approximately every 18 24 months. This exponential growth has not yet saturated and Moore's law is still valid. At the present time the limit is approximately 10^8 transistors per chip and the typical size of circuit components is of the order of 100 nanometres. Extrapolating Moore's law, one would estimate that around the year 2020 we shall reach the atomic size for storing a single bit of information. At that point, quantum effects will become unavoidably dominant.

One should be aware that, besides quantum effects, other factors could bring Moore's law to an end. In the first place, there are economic considerations. Indeed, the cost of building fabrication facilities to manufacture chips has also increased exponentially with time. Nevertheless, it is important to understand the ultimate limitations set by quantum mechanics. Even though we might overcome economic barriers by means of technological breakthroughs, quantum physics sets fundamental limitations on the size of the circuit components. The first question under debate is whether it would be more convenient to push the silicon-based transistor to its physical limits or instead to develop alternative devices, such as quantum dots, single-electron transistors or molecular switches. A common feature of all these devices is that they are at the nanometre length scale, and therefore quantum effects play a crucial role.

So far, we have talked about quantum switches that could substitute silicon-based transistors and possibly be connected together to execute classical algorithms based on Boolean logic. In this perspective, quantum effects are simply unavoidable corrections that must be taken into account owing to the nanometre size of the switches. *A quantum computer represents a radically different challenge:* the aim is to build a machine based on quantum logic, that is, a machine that can process the information and perform logic operations in agreement with the laws of quantum mechanics.

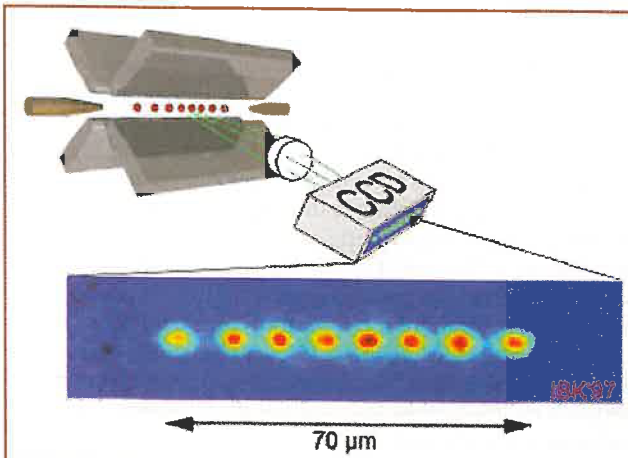
Quantum logic

The elementary unit of quantum information is the *qubit* (the quantum counterpart of the classical bit) and a quantum computer may be viewed as a many-qubit system. Physically, a qubit is a two-level system, like the two spin states of a spin - $\frac{1}{2}$ particle, the vertical and horizontal polarization states of a single photon or two states of an atom.

A classical bit is a system that can exist in two distinct states, which are used to represent 0 and 1, that is, a single binary digit. The only possible operations (gates) in such a system are the identity ($0 \rightarrow 0, 1 \rightarrow 1$) and NOT ($0 \rightarrow 1, 1 \rightarrow 0$). In contrast, a quantum bit (qubit) is a two-level quantum system, described by a two-dimensional complex Hilbert space. In this space, one may choose a pair of normalized and mutually orthogonal quantum states, called $|0\rangle$ and $|1\rangle$, to represent the values 0 and 1 of a classical bit. These two states form a computational basis. From the *superposition principle*, any state of the qubit may be written as

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \quad (1)$$

where the amplitudes α and β are complex numbers, constrained by the normalization condition $|\alpha|^2 + |\beta|^2 = 1$.



▲ Fig. 1: Schematic drawing of a string of qubits (ions) in a linear trap. The ions are confined by a combination of static and oscillating electric fields. In order to detect the ions, they are illuminated with a suitable laser beam: part of the fluorescence photons emitted by the ions are collected by a lens and sent to a CCD camera. At the bottom, an image of ions trapped in an experiment is shown. (Courtesy of Rainer Blatt, University of Innsbruck)

The collection of n qubits is known as a *quantum register* of size n. Its wave function resides in a 2^n-dimensional complex Hilbert space. While the state of an n-bit classical computer is described in binary notation by an integer $k \in \{0,1,...,2^n-1\}$,

$$k = k_{n-1}\, 2^{n-1} + \cdots + k_1\, 2 + k_0, \quad (2)$$

with $k_0, k_1, \ldots, k_{n-1} \in \{0,1\}$ binary digits, the state of an n-qubit quantum computer is

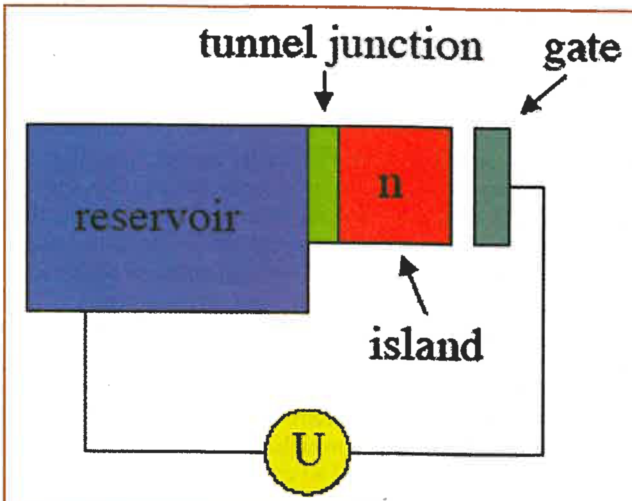
$$|\psi\rangle = \sum_{k=0}^{2^n-1} c_k\, |k\rangle, \quad (3)$$

where $|k\rangle \equiv |k_{n-1}\rangle \cdots |k_1\rangle\, |k_0\rangle$, with $|k_j\rangle$ state of the j-th qubit, and $\sum_{k=0}^{2^n-1} |c_k|^2 = 1$,

The superposition principle is clearly visible in Eq. (3): while n classical bits can store only a single integer k, the n-qubit quantum register can be prepared in the corresponding state $|k\rangle$ of the computational basis, but also in a superposition. We stress that the number of states of the computational basis in this superposition can be as large as 2^n, which grows exponentially with the number of qubits. The superposition principle opens up new possibilities for computation. When we perform a computation on a classical computer, different inputs require separate runs. In contrast, a quantum computer can perform a computation for exponentially many inputs on a single run. This huge parallelism is the basis of the power of quantum computation.

It is also important to point out the role of *entanglement* for the power of quantum computation, as compared to any classical computation. Entanglement is the most spectacular and counter-intuitive manifestation of quantum mechanics, observed in composite quantum systems: it signifies the existence of non-local correlations between measurements performed on well-separated particles. After two classical systems have interacted, they are in well-defined individual states. In contrast, after two quantum particles have interacted, in general, they can no longer be described independently of each other. There will be purely quantum correlations between two such particles, independently of their spatial separation. Examples of two-qubit entangled states are the four states of the so-called Bell basis, $|\phi^{\pm}\rangle = \frac{1}{2}(|00\rangle \pm |11\rangle)$ and $|\psi^{\pm}\rangle = \frac{1}{2}(|01\rangle \pm |10\rangle)$. The measure of the polarization state of one qubit will instantaneously affect the state of the other qubit, whatever their distance is. There is no entanglement in classical physics. Therefore, in order to represent the superposition of 2^n levels by means of classical waves, these levels must belong to the same system. Indeed, classical states of separate systems can never be superposed. Thus, to represent the generic n-qubit state (3) by classical waves we need a single system with 2^n levels. If Δ is the typical energy separation between two consecutive levels, the amount of energy required for this computation is given by $\Delta 2^n$. Hence, the amount of physical resources needed for the computation grows exponentially with n. In contrast, due to entanglement, in quantum physics a general superposition of 2^n levels may be represented by means of n qubits. Thus, the amount of physical resources (energy) grows only linearly with n.

In conclusion, due to superposition and entanglement, a quantum computer could, in principle, lead to an exponential speed up with respect to classical computation. The next question is how to implement a quantum computation. For this purpose, we must be able to control the evolution in time of the many-qubit state describing the quantum computer. As far as the coupling to the environment may be neglected, this evolution is unitary and



▲ Fig. 2: Schematic drawing of a Josephson-junction qubit in its simplest design: a small superconducting island with n excess Cooper pairs (relative to some reference state) is connected by a tunnel junction with capacitance C_J and Josephson coupling energy E_J to a superconducting reservoir. The junction is biased by a gate voltage U with gate capacitance C_g

governed by the Schrödinger equation. It is well known that, on a classical computer, a small set of elementary logic gates allows the implementation of any complex computation. This is very important: it means that, when we change the problem, we do not need to modify our computer hardware. Fortunately, the same property remains valid for a quantum computer. It turns out that each unitary transformation acting on a many-qubit system can be decomposed into unitary quantum gates acting on a single qubit and a suitable quantum gate acting on two qubits, for instance the controlled-NOT (CNOT) gate. The CNOT is a two-qubit gate, defined as follows: it turns $|00\rangle$ into $|00\rangle$, $|01\rangle$ into $|01\rangle$, $|10\rangle$ into $|11\rangle$ and $|11\rangle$ into $|10\rangle$. As in the classical XOR gate, the CNOT gate flips the state of the second (target) qubit if the first (control) qubit is in the state $|1\rangle$ and does nothing if the first qubit is in the state $|0\rangle$. It is easy to see that CNOT can generate entangled states. For example, if we apply CNOT to the non-entangled state $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)|0\rangle$, we obtain the Bell state $\frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$.

Quantum algorithms

As we have seen, the power of quantum computation is due to the inherent *quantum parallelism* associated with the superposition principle. In simple terms, a quantum computer can process a large number of classical inputs in a single run. However, it is not an easy task to extract useful information from the output state. The problem is that this information is, in a sense, hidden. Any quantum computation ends up with a projective measurement in the computational basis. The output of the measurement process is inherently probabilistic and the probabilities of the different possible outputs are set by the basic postulates of quantum mechanics. However, there exist quantum algorithms that efficiently extract useful information.

In 1994, Peter Shor proposed a quantum algorithm that efficiently solves the prime-factorization problem [3]: given a composite odd positive integer N, find its prime factors. This is a central problem in computer science and it is conjectured, though not proven, that for a classical computer it is computationally difficult to find the prime factors. Shor's algorithm efficiently solves the integer factorization problem in $O((n^2\log n\log \log n))$ elementary quantum gates, where n=logN is the number of bits necessary to code the input N. Therefore it provides an exponential improvement in speed with respect to any known classical algorithm. Indeed, the best classical algorithm, the number field sieve, requires $\exp(O(n^{1/3}(\log n)^{2/3}))$ operations. It is worth mentioning that there are cryptographic systems, such as RSA, that are used extensively today and that are based on the conjecture that no efficient algorithms exist for solving the prime factorization problem. Hence Shor's algorithm, if implemented on a large scale quantum computer, would break the RSA cryptosystem.

Other quantum algorithms have been developed. In particular, Grover has shown that quantum computers can also be useful for solving the problem of searching for a marked item in an unstructured database of $N=2^n$ items [4]. The best we can do with a classical computer is to go through the database, until we find the solution. This requires $O(N)$ operations. In contrast, the same problem can be solved by a quantum computer in $O(\sqrt{N})$ operations. In this case, the gain with respect to classical computation is quadratic.

A third relevant class of quantum algorithms is the simulation of physical systems. It is well known that the simulation of quantum many-body problems on a classical computer is a difficult task as the size of the Hilbert space grows exponentially with the number of particles. For instance, if we wish to simulate a chain of n spin - $\frac{1}{2}$ particles, the size of the Hilbert space is 2^n. Namely, the state of this system is determined by 2^n complex numbers. As observed by Feynman in the 1980's, the growth in memory requirement is only linear on a quantum computer, which is itself a many-body quantum system. For example, to simulate n spin - $\frac{1}{2}$ particles we only need n qubits. Therefore, a quantum computer operating with only a few tens of qubits can outperform a classical computer. Of course, this is only true if we can find efficient quantum algorithms to extract useful information from the quantum computer. Quite interestingly, it has been shown that a quantum computer can be useful not only for the investigation of the properties of many-body quantum systems, but also for the study of the quantum ad classical dynamics of complex single-particle systems (for a recent review see, e.g., [5]).

First experimental implementations

The great challenge of quantum computation is to experimentally realize a quantum computer. Many requirements must be fulfilled in order to achieve this imposing objective. We require a collection of two-level quantum systems that can be prepared, manipulated and measured at will. That is, our purpose is to be able to control and measure the state of a many-qubit quantum system. A useful quantum computer must be *scalable* since we need a rather large number of qubits to perform non-trivial computations. In other words, we need the quantum analogue of the integrated circuits of a classical computer. Qubits must interact in a controlled way if we wish to be able to implement a universal set of quantum gates. Furthermore, we must be able to control the evolution of a large number of qubits for the time necessary to perform many quantum gates. Given the generality of the requirements to build a quantum computer, many physical systems might be good candidates

In liquid state Nuclear Magnetic Resonance (NMR) quantum processors [2], the quantum hardware consists of a liquid containing a large number (of order 10^{18}) of molecules of a given type, placed in a strong static magnetic field. A qubit is the spin of a nucleus in a molecule and quantum gates are implemented by means of resonant oscillating magnetic fields (Rabi pulses), that is, NMR techniques are used. Quantum information exchange between nuclei inside a molecule is based on spin-spin interactions (chemical bonds) between neighbouring atoms. The molecules are prepared in thermal equilibrium at room temperature. It is important to stress that in liquid-state NMR the spin state of a single nucleus is neither prepared nor measured. On the contrary, we measure the average spin state of the $\sim 10^{18}$ molecules contained in the solution. With NMR experiments, it has been possible to experimentally demonstrate several quantum algorithms, including Grover's algorithm, the quantum Fourier transform and the Shor's algorithm, using from three- to seven-qubit molecules. Unfortunately, liquid-state NMR quantum computing is not scalable since the measured signal drops exponentially with the number of qubits in a molecule.

Using cavity quantum electrodynamics (QED) techniques [6], it has been possible to realize experiments in which a single atom interacts with a single mode or a few modes of the electromagnetic field inside a cavity. The two states of a qubit can be represented by the polarization states of a single photon or by two excited states of an atom. Cavity QED techniques have allowed the implementation of one and two-qubit gates and have been particularly successful in demonstrating basic features of quantum mechanics, such as entanglement, or in exploring the transition from the quantum world to classical physics.

Several other proposals have been put forward to build a quantum computer, including quantum optics approaches, cold atoms in optical lattices and solid-state systems such as quantum dots and spin in semiconductors. It is too early to say which route will be the most suitable to build a scalable quantum hardware. Due to space limitations, we limit ourselves to discuss in more detail two implementations for which major advances have recently occurred: cold ions in a trap and superconducting circuits.

Ion traps

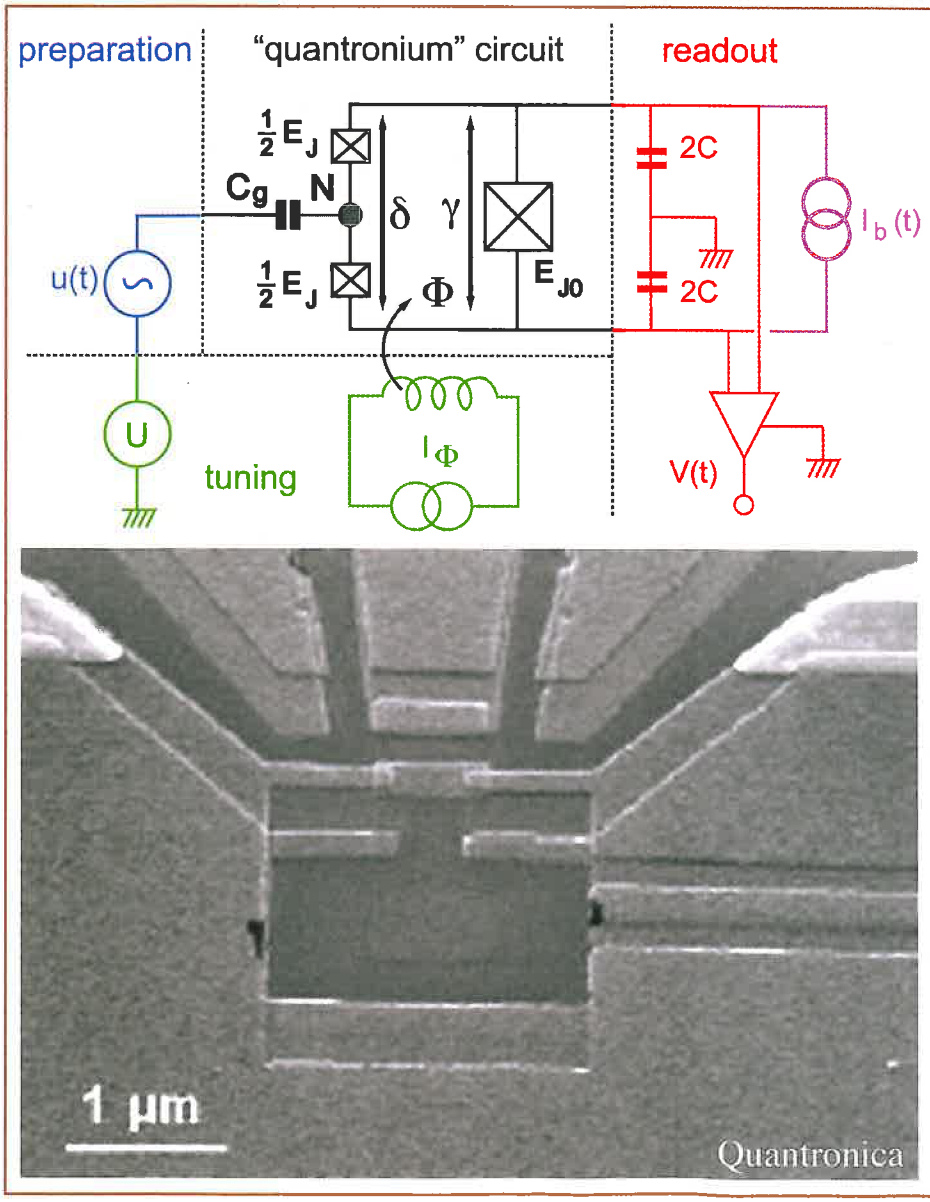
The quantum hardware is as follows: a string of ions is confined by a combination of static and oscillating electric fields in a linear trap (known as a Paul trap, see Fig.1). A qubit is a single ion and two long-lived states of the ion correspond to the two states of the qubit. The linear array of ions held in the trap is the quantum register. The initialization of all the qubits in the state $|0\rangle$ is possible by means of optical-pumping techniques: When an ion is in a state different from $|0\rangle$, it absorbs a photon and then decays, this process being repeated until each ion reaches the $|0\rangle$ state. After a quantum computation, the state of each ion can be measured using *quantum jump* detection: each ion is illuminated with laser light of polarization and frequency such as it absorbs and then reemits photonsonly if it is in the state $|1\rangle$. In contrast, if it is in the state $|0\rangle$ the laser frequency is out of resonance and does not induce any transition. Thus, the detection of fluorescence indicates that the ion was in the state $|1\rangle$.

Single-qubit gates are obtained by addressing individual ions with laser pulses of appropriate frequency, intensity and duration. The interactions between qubits, which are necessary to implement controlled two-qubit operations, are mediated by the collective vibrational motion of the trapped string of ions. To implement the two-qubit CNOT gate, Cirac and Zoller proposed the following scheme. The quantum state of the control qubit (ion) is mapped onto the vibrational state of the whole string (known as *bus-qubit*), with the use of laser beams focused on that ion. A gate operation can then be performed between the bus qubit and the target ion. We should stress that this is possible because also the target qubit participates to the collective vibrational motion. As a result, the effect of a laser beam on the target qubit depends on the state of the bus-qubit. Finally, this state is mapped back onto the control ion. Note that the preparation of the ground state of the bus-mode is nowadays possible with great accuracy using laser cooling techniques.

The Cirac-Zoller CNOT gate was realized by the Innsbruck group [7], using two $^{40}Ca^{+}$ ions held in a linear trap and individually addressed using laser beams. A generic single-qubit state is encoded in a superposition of the ground state $S_{1/2}$ and the metastable state $D_{5/2}$ (whose lifetime is approximately 1 s). More recently, scientists at NIST, Boulder and at Innsbruck were able to implement *quantum teleportation* between a pair of trapped ions [8,9]. Teleportation exploits entanglement and provides a means to transport quantum information (a quantum state) from one location to another, without transfer of the physical system that carries the quantum information. This possibility could be of practical interest for quantum computation, for example in the transfer of quantum information between different units of a quantum computer.

Sources of errors in ion-trap quantum computation are the heating due to stochastically fluctuating electric fields, the ambient magnetic field fluctuations and the laser frequency noise. At present, the implementation of the CNOT gate by a sequence of 8 laser light pulses requires approximately 500 μs, while the decoherence time scale is of the order of 1 ms. Here the termdecoherence (or loss of quantum coherence) denotes the corruption of the quantum information stored in the quantum computer, due to the unavoidable coupling of the quantum computer to the surrounding environment [10]. Using ions less susceptible to environmental influences, it seems probable that in the next few years it will become possible to apply tens of quantum gates to a few ions without loosing quantum coherence.

The scaling to large qubit numbers is envisaged by using arrays of interconnected ions traps. The communication between the traps could be achieved by photon interconnection or by moving ions from one trap to another. In the first case, the state of a qubit would be transferred from an ion in a trap to a photon and then from the photon to a second ion in another trap. In the latter case, ion qubits would be moved from one trap to another by application of suitable electric fields. It seems that there are no fundamental physical obstacles against these proposals, but a significant technological challenge remains.



◄ **Fig. 3:** Left: Schema of a superconducting circuit, nicknamed "quantronium", that behaves as a two-level system. The circuit consists of a superconducting island (black dot) delimited by two small Josephson junctions (crossed boxes) in a superconducting loop. The loop also includes a third, larger Josephson junctions. E_J and E_{J0} denote the Josephson energies of the Cooper pair box and of the large junction, respectively. The number N of Cooper pairs in the island and the superconducting phases δ and γ are the degrees of freedom of the circuit. A current I_Φ applied to a coil produces a flux Φ in the circuit loop and is used to tune the quantum energy levels. Microwave pulses $u(t)$ are applied to the gate to prepare arbitrary states of the qubit. These states are readout by applying a current pulse $I_b(t)$ to the large junction and by monitoring the voltage $V(t)$ across it. Right: Scanning electron micrograph of a sample made of aluminum and aluminum oxide. The gate electrode is at the top and the island is below the gate. The large junction is the wide rectangle at the right side. (Courtesy of Daniel Esteve, CEA, Saclay)

Superconducting circuits

Several proposals have been put forward to build a solid-state quantum computer. This is not surprising, since solid-state physics has developed over the years a sophisticated technology, creating artificial structures and devices on nanoscale. Solid-state physics is at the basis of the development of classical computer technology and therefore the scalability problem would find a natural solution in a solid state quantum computer. Indeed, such a quantum computer could benefit from the fabrication techniques of microelectronics.

Recently there has been very remarkable experimental progress using superconducting microelectronic circuits to construct artificial two-level systems [11]. In superconductors, pairs of electrons are bound together to form objects of charge twice the electron charge, called Cooper pairs. Electrostatic potentials can confine the Cooper pairs in a "box" of micron size. In a Josephson junction a Cooper pair box, known as the island, is connected by a thin insulator (tunnel junction) to a superconducting reservoir (see Fig.2). Cooper pairs can move from the island to the reservoir and vice versa by quantum tunneling effect. They enter the island one by one when a control gate electrode, capacitively coupled to the island, is varied. The island has discrete quantum states and, under appropriate experimental conditions, the two lowest energy states $|0\rangle$ and $|1\rangle$ form a two-level system suitable for a qubit. An improved Cooper pair box circuit acting as a qubit is shown in Fig.3. By applying microwave pulses to the gate electrode, this qubit can be prepared in any coherent superposition $\alpha|0\rangle+\beta|1\rangle$. The manipulation of one-qubit states is possible: a microwave resonant pulse of duration τ induces controlled Rabi oscillations between the states $|0\rangle$ and $|1\rangle$. If τ is appropriate, the NOT gate ($|0\rangle\rightarrow|1\rangle, |1\rangle\rightarrow|0\rangle$) is implemented. A Ramsey fringe experiment has also allowed to measure the decoherence time scale $t_d \approx 0.5\ \mu s$ for this circuit [12]. This time is much longer than the time required to implement a single-qubit gate, so that an arbitrary evolution of the two-level system can be implemented with a series of microwave pulses. Note that the time for a single qubit operation can be made as short as 2 ns. More recently, a two-qubit gate was operated using a pair of capacitively coupled superconducting qubits [13].

Outlook

To summarize, the main question under discussion is: is it possible to build a useful quantum computer that could outperform existing classical computers in important computational tasks? And, if so, when? The difficulties are huge. Besides the problem of decoherence, we should also remark on the difficulty of finding new and efficient quantum algorithms. We know that the integer-factoring problem can be solved efficiently on a quantum computer, but we do not know the answer to the following fundamental question: What class of problems could be simulated efficiently on a quantum computer? Quantum computers open up fascinating prospects, but it does not seem likely that they will become a reality with practical applications in a few years. How long might it take to develop the required technology? Even though unexpected technological breakthroughs are, in principle, always possible, one should remember the enormous effort that was necessary in order to develop the technology of classical computers.

Nevertheless, even the first, modest, demonstrative experiments are remarkable, not only for quantum computation but also for testing the theoretical principles of quantum mechanics. Since quantum mechanics is a particularly counter-intuitive theory, we should at the very least expect that experiments and theoretical studies on quantum computation will provide us with a better understanding of quantum mechanics. Moreover, such research stimulates the control of individual quantum systems (atoms, electrons, photons *etc.*). We stress that this is not a mere laboratory curiosity, but has interesting technological applications. For instance, it is now possible to realize single-ion clocks that are more precise than standard atomic clocks. Other foreseen applications are the use of entangled states to improve the resolution of optical lithography and interferometric measurements.

Quantum mechanics also provides a unique contribution to cryptography: it enables two communicating parties to detect whether the transmitted message has been intercepted by an eavesdropper. This is not possible in the realm of classical physics as it is always possible, in principle, to copy classical information without changing the original message. In contrast, in quantum mechanics the measurement process, in general, disturbs the system for fundamental reasons: this is a consequence of the Heisenberg uncertainty principle. Experimental advances in the field of quantum cryptography are impressive [14] and quantum-cryptographic protocols have been demonstrated, using optical fibres, over distances of a few tens of kilometres at rates of the order of a thousand bits per second. Furthermore, free-space quantum cryptography has been demonstrated over distances up to several kilometres. In the near future, therefore, quantum cryptography could well be the first quantum-information protocol to find commercial applications.

To conclude, the time when a quantum computer will be on the desk in our office is uncertain. What is certain is that an exciting and very promising field of investigation has been opened. Finally, let us quote Schrödinger [Brit. J. Phil. Sci. 3, 233 (1952)]: *"We never experiment with just one electron or atom or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences ... we are not experimenting with single particles, any more than we can raise Ichthyosauria in the zoo"*. It is absolutely remarkable that only fifty years later experiments on single electrons, atoms and molecules are routinely performed in laboratories all over the world.

References

* Electronic address: giuliano.beneti@uninsubria.it
† Electronic address: giulio@ uninsubria.it

[1] G. Benenti, G. Casati and G. Strini, Principles of Quantum Computation and Information, Vol. I: Basic Concepts (World Scientific, Singapore, 2004).

[2] M.A. Nielsen and I.L. Chuang, Quantum computation and quantum information (Cambridge University Press, Cambridge, 2000).

[3] G. Benenti, G. Casati and S. Montangero, quant-ph/0402010.

[4] J.M. Raimond, M. Brune and S. Haroche Rev. Mod. Phys. 73, 565 (2001).

[5] F. Schmidt-Kaler et al., Nature 422, 408 (2003).

[6] M. Riebe et al., Nature 429, 734 (2004).

[7] M.D. Barrett et al., Nature 429, 737 (2004).

[8] W.H. Zurek, Rev. Mod. Phys. 75, 715 (2003).

[9] Y. Makhlin, G. Schön, and A. Shnirman, Rev. Mod. Phys. 73, 357 (2001).

[10] D. Vion et al., Science 296, 886 (2002).

[11] T. Yamamoto et al., Nature 425, 941 (2003).

[12] N. Gisin et al., Rev. Mod. Phys. 74, 145 (2002).

Neutrino mass, radioactivity and the dating of wine

Philippe Hubert, CENBG/IN2P3 – Université Bordeaux 1, France

A few weeks ago, when listening to the radio, I heard a journalist interviewing a physicist on the now very familiar fundamental particle called the neutrino. Following the customary explanations about the origin of the particle, its properties (charge, mass, etc…) and its role in nature, or more precisely its role in the Universe, the journalist made a final remark. 'Working on neutrino properties looks very exciting, but it seems to be of absolutely no use in our practical life'. 'You are absolutely wrong', answered the physicist, 'don't you believe it. As an example, I can tell you that some of the techniques developed in this research are now being used to date wine!'

Since neutrinos are chargeless particle and only sensitive to the weak interaction, they are very difficult to detect, and therefore the physics of the neutrino generally involves very large and difficult experiments. Some of them study naturally occurring sources of neutrinos, such as the sun or cosmic neutrinos, while others use neutrinos from artificial sources such as nuclear reactors or particle accelerators. One of the main challenges of this physics is the mass of the neutrino. At the present time, from the recently published results of several neutrino oscillation experiments, the mass appears to be non-zero, but very small. Another, but indirect way to study neutrino mass is to look for a process called double-beta decay. (In ordinary beta decay a nucleus emits an electron, always accompanied by an anti-neutrino). If a nucleus can emit simultaneously two electrons (with no anti-neutrinos), it implies necessarily that the mass of the neutrino is non-zero, and the frequency (or period) of the decay will give the absolute scale. Until now neutrinoless double-beta decay has not been observed. The limits on the periods lead to a mass lower than 0.5 eV, i.e., one million times less than the electron mass, the next heaviest particle. A double-beta decay experiment call NEMO (Neutrino Experiment with MOlybdenum), in which our group is involved, is now running in the Modane underground laboratory in France. A second one called CUORE, with a totally different technique, is in progress in the Gran Sasso laboratory in Italy and several others are being developed around the world.

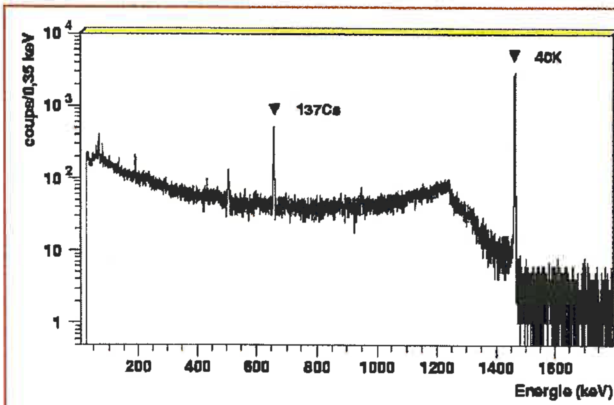
All these experiments have the common feature that they are looking for a very weak signal among a large number of parasitic signals. The physicists involved become rapidly obsessed with the background noise. First of all in order to suppress any effect of the cosmic rays (and the induced neutrons) almost all the experiments have to be installed in deep underground laboratories. Then the detectors have to be protected against the radiation (gamma rays and the remaining neutrons) coming from the surrounding materials, which is achieved by surrounding them with shields made generally of pure lead or iron, or sometimes with water tanks or light Z materials. A third background component is given by the radioactive gas radon that is naturally contained in the air at the level of few Bq/m3. Generally the level of radon has to be decreased by 3 or 4 orders of magnitude, using cold charcoal devices. Finally, the detector itself should be built out of materials containing "no" or only infinitesimal quantities of naturally occurring radioactive elements, such as U, Th, Ra, and their daughters.

Low-background gamma-ray spectrometry

Most of these aforesaid natural radioactive nuclei are gamma emitters. So, in order to be able to select and control the level of radioactive contaminants in materials our group at the University of Bordeaux has been involved over several years in the development of low background gamma-ray spectrometers (in collaboration with an industrial company). Then, hundreds of materials such as metals, glasses, electronics components, glues, screws, etc…have been measured. The expression "low background" in terms of sensitivity means being able to measure activities down to 10 microBq/kg, i.e., about 6 orders of magnitude less than the average level in nature. One may note that the human body contains about 100 Bq/kg, half due to ^{40}K and half to ^{14}C; and in some mushrooms up to 1000 Bq/kg of ^{137}Cs have been recently measured, even almost 20 years after the Chernobyl accident!

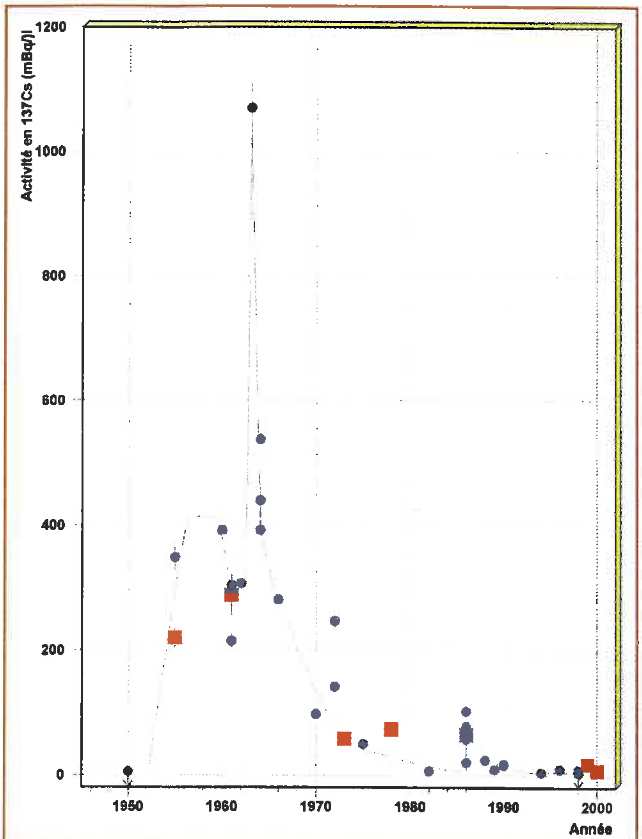
The most common technique for gamma-ray spectrometry is based on very pure, large volume germanium crystals (up to 1000 cm^3) cooled down to liquid nitrogen temperature in a special cryostat. The crystal operates like an electronic diode in the reverse bias mode. Any gamma-ray will interact with the crystal through the three most important absorption processes, the photoelectric effect, the Compton effect and the pair-production effect. After interaction the electrons recoil in the crystal, resulting in the creation of electron-hole pairs, which give an electronic pulse whose amplitude is proportional to the absorbed energy. These analogue pulses are then digitised and give an energy spectrum as shown in fig. 1. Any gamma-ray emitted from a radioactive nucleus will give a line in the spectrum with a well defined energy and an intensity proportional to the activity.

In order to be able to measure very low activities, the cryostat is made with highly selected "non-radioactive" materials, is surrounded with a heavy shielding and finally is installed in an underground location. Depending on the required sensitivity, underground means under a mountain such as at Modane (1700 m of rock) or in the basement of a research building at the university of Bordeaux (in this case only a few meters of concrete). In the latter case, a cosmic ray veto made of large plastic scintillators is added to the experimental device. Moreover, special care



▲ Fig. 1: Typical gamma-ray energy spectrum of a wine sample recorded with a Ge spectrometer.
The 1461 keV ^{40}K and 661 keV ^{137}Cs lines are clearly visible.

features



▲ Fig. 2: Activity (mBq/l) of the ^{137}Cs radioactive isotope as a function of the wine millésime. All activities are normalised to the same date, the 1/1/2000. The blue points correspond to measurements after reduction of the wine into ashes, the red squares correspond to non destructive measurements, without opening the bottles. Statistical errors are generally smaller than the dimensions of the points. Points connected with downward arrows are only limits.

has to be taken against any radon penetration inside the shielding. Times of measurements may vary from one day to one month depending on the amount of activity in the sample, and the required sensitivity.

Dating of wine

Such sensitivity in the detection of radioactive isotopes was of obvious interest for other disciplines than physics, and several laboratories in oceanography, geology, archeology, environmental sciences and ...oenology are now currently using these low background gamma ray spectrometers. Why also oenology? It is well known that measuring radioactivity opens the possibility of dating, and therefore why not measuring the radioactivity of a bottle of wine and verify the year or "millésime" written on the label?

Indeed the problem of dating a wine using radioactive techniques is not new: already in 1954 Kaufman and Libby (Nobel prize in 1960 for the ^{14}C dating technique) used tritium ($T_{1/2}$ = 12.3 y) to date several French and Italian wines [1]. About 25 years later, P. Martinière et al. [2] used the ^{14}C isotope to date several Bordeaux wines. The procedure is based on the fact that the amount of ^{14}C in the atmosphere increased by about a factor of 2 after the atmospheric nuclear tests (1950-1963), and then decayed regularly. However these techniques need the bottles to be opened and a sample to be prepared from distillation. Moreover the tritium technique is nowadays more difficult due to the fallout from nuclear reactors, and the ^{14}C technique can give a wrong dating result where there has been the addition of any product such as sugar. As a consequence, the DGCCRF[1] asked if it was not possible to find through our low background gamma-ray spectrometers another possibility for dating. This explains why, when seeking to measure the mass of the neutrino, one opens a bottle of fine old Bordeaux wine to measure its radioactivity!

In order to obtain the best available sensitivity, the first measurements were made after evaporation of the wine, and burning the residue into ashes. The first results showed that wine essentially contains the isotope ^{40}K (see fig. 1) at the level of 30 Bq/l, which corresponds to about 0.9 g of natural potassium in each liter of wine. There is nothing surprising about that, since wine contains, even if connoisseurs may not like it, a fair amount of potassium bi-tartrate. But far more surprising was the fact that certain bottles of wine contain also the isotope ^{137}Cs ($T_{1/2}$ = 30 y), a man-made radioactive isotope, whose origin is from nuclear fission. Even more interesting was the fact that the amount (or activity) varies as a function of the year. All that remained to do was to find a set of bottles with certified "millésimes" and to carry out measurements of the ^{137}Cs radioactivity as a function of the year. The curve shown in fig. 2 was readily obtained [3]. First, wine connoisseurs can reassure themselves, the observed activities are small, always less than 1 Bq/l. Then the results show that the wine keeps a memory of atmospheric nuclear testing (the years 1950-1963) and the accident of Chernobyl (1986). It is obvious that such a curve can be exploited to estimate the age of a given wine, at least to control the year written on the label, and possibly to detect any anomalies. For example, any wine before 1950 should not contain any detectable ^{137}Cs activity!

Even if established only with Bordeaux wines, we think that the 1950-1985 part of the curve can be used for any wine from the northern countries since the ^{137}Cs reservoir is the high atmosphere. For 1986 and beyond, it is well known that the ^{137}Cs fallout due to Chernobyl is strongly dependent of the geographical localization. For example, within the 1986 Bordeaux wines, the ^{137}Cs activity varies from a few mBq/l up to a 100 mBq/l. For French eastern 1986 wines the activity may even reach up to 1000 mBq/l!

At this point it is important to remark that dating using the ^{137}Cs activity from nuclear fallout is not new, but is already used in other disciplines, such as in geology to date sediments. What is new with our technique is the possibility to measure activities down to a few mBq/l

Non-destructive dating of wine

Even if the process of reduction of a wine into ashes is rather easy, it cannot be systematically used, specially with old "grands crus" for which prices can be rather expensive. And beside the price, everybody would prefer to taste and drink such a wine than to reduce it into ashes. Therefore it became rapidly important to work on a non-destructive way of dating.

In principle there is no argument against such a non-destructive measurement since the energy of the gamma-ray emitted by the ^{137}Cs nucleus, 661 keV, is high enough to escape the wine and to cross the glass of the bottle before to making an interaction with the Ge crystal. It is only necessary to set a bottle close to the endcap of the detector, and to record the energy spectrum. Fig. 3 shows the set-up currently used in Bordeaux, where up to four

[1] Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes, a French government agency charged with protecting consumers, assuring fair competition and preventing fraud.

identical bottles can be measured at the same time. However, such a procedure implies a serious loss in the sensitivity of the measurement: firstly because the geometry of the source becomes quite large, and secondly, because the rather high level of radioactivity in the glasses (^{40}K, U, Th, Ra and their daughters) increases the background of the spectra. Nevertheless the first measurements have shown that within these experimental conditions, the ^{137}Cs gamma line is still observable down to an activity of 20 mBq/l. The first activities measured this way are shown in fig. 2 as red squares and are in very good agreement with the values obtained from the ashes. Of course we have carefully checked that neither the glass nor the cork themselves contain strong ^{137}Cs contaminations.

Summary and outlook

Since the pioneering measurements given in fig. 2, much more data have been accumulated, mainly for Bordeaux wine. For a given year some dispersion in the activity values is observed, due to statistics and to non-uniformity in the ^{137}Cs fallout which depends on the local amount of rain or aerosols. However the average values are always very close to the curve of fig. 2, and therefore now we consider that the method is validated.

Of course we are well aware that the curve of fig. 2 is not without any ambiguities. A measured ^{137}Cs activity of 100 mBq/l may correspond to the years 1953 (rare!), 1970 or 1986. Another weak point is that the ^{137}Cs activity in a "young" wine, beyond 1985, is rather low and/or strongly dependent on the Chernobyl fallout. But this curve is the only data available that is provided by human activity! For a particular analysis, we would recommend that first a non-destructive measurement should be carried out, and if the answer is not satisfactory, then one can always reduce the sample into ashes and proceed to a more sensitive gamma analysis.

Nowadays we are working on the possibility to use another radioactive isotope that is also present in wine, namely ^{210}Pb ($T_{1/2} = 22$ y). The origin of this isotope is the radon inside the air. After decay, the radon daughters, such as ^{210}Pb are fixed on dusts or aerosols and then fall down on the soil, plants, grapes, and finally enter the wine. If we know the amount of ^{210}Pb at the time the wine is bottled ($t = 0$), then dating is possible using simply the exponential law of decay. However, there are several drawbacks with this method: 1) the activity at the time $t = 0$ is rather weak, around 100 mBq/l which implies the need for very precise activity measurements; 2) until now we don't know if the $t = 0$ activity is constant with the year and with the "terroir"; 3) the gamma-ray emitted in the decay of ^{210}Pb is rather weak in intensity (4%) and low in energy (46 keV) and therefore only measurements with a wine reduced into ashes can be envisaged; and 4) the 30 Bq/l of ^{40}K, always present in the wine, gives a severe high background level in the gamma spectra, due to the Compton of the 1461 keV gamma (10% of the decays), and to the bremsstrahlung of the beta-rays (90% of the decays). Nevertheless, recent measurements with a new low-background well-type Ge spectrometer appear to be encouraging.

Finally, it is important to stress that with the present sensitivities, i.e., around 1 mBq/l, obtained with this new low-background well-type Ge spectrometer, a few other natural radioactive isotopes are simultaneously observed in the same spectra, such as Ra, Th and their progenies. The activities are even lower, around 10-20 mBq/kg, but still easily measurable. From the equilibrium situation within the chains we obtain again new information on the age of the wine. As a result, with our present sensitivities, we obtain within the same gamma ray spectrum three or four independent possibilities to date a wine (^{137}Cs, ^{210}Pb, radium and thorium isotopes), and we hope to obtain the necessary accuracy to one year, even for young wines. However many more measurements are still necessary before the method can be validated. And now, we are wondering if these levels of radioactivity could not also be a signature of the "terroir"?

A suivre... as we say in France!

References

[1] S. Kaufman, W.L.Libby, Physical Review, 93, No. 6, (1954) 1337.

[2] P. Martinière, et al., Annales des falsifications, de l'expertise chimique et toxicologique, 72 (1979)263.

[3] Ph. Hubert, et al., Annales des falsifications, de l'expertise chimique et toxicologique, 94 (2001)357.

▲ **Fig. 3:** View of the experimental set-up for a non-destructive dating measurement of the wine. The Ge crystal is kept in vacuum inside the aluminium cap, in the center of the picture. With this device up to 4 identical bottles can be measured at the same time, and the sensitivity in the ^{137}Cs measurement is around 20 mBq/l.

features

Getting ready for Framework 7

Sean McCarthy (sean.mccarthy@hyperion.ie)

Framework 6 (the European Union's Research and Development Programme) started in 2003 and will finish at the end of 2006. Framework 7 is expected to begin in 2007. The formal political process that will be used to prepare Framework 7 will take approximately two years to complete. In addition to the formal process, many studies, reviews, evaluations and assessments will be undertaken to decide on the structure, priorities and content of the programme. This article provides an overview of the process that will be used to prepare Framework 7. It will also describe the new directions of the programme. The websites mentioned in this paper can be found on www.hyperion.ie/fp7websites.htm

How Framework 7 will be prepared.

Figure 1 shows the different players involved in the preparation of Framework 7. Between 2004 and 2006, the budget, structure and rules for Framework 7 will be decided by the European Commission and the Political Institutions (the European Parliament and the Council of Ministers). When this process is complete, the European Commission will 'implement' the programme between 2007 and 2011.

The following diagrams will show the individual steps involved in the preparation of Framework 7 and will then identify how researchers can contribute to the debate or monitor the progress of the debate.

Step 1. The European Commission will 'Propose' FP7

In early 2005, the European Commission will formally publish a 'Proposal for the Framework 7 Programme' (Figure 2). This is one of the Commission main powers – no debate on any new programme or policy can start until they are ready.

Step 2. The European Parliament is 'Consulted'

The 'Proposal' is sent to the European Parliament for consultation (Figure 3). Here the Parliament can totally 'reject' the proposal or it can recommend 'amendments'. When the proposal for Framework 6 was first submitted – the European Parliament gave it over 600 amendments. The 'Proposal for Framework 7' will be returned to the European Commission and an 'Amended Proposal for Framework 7' will be submitted some months later. Again there will be more 'amendments' by the European Parliament. This process will continue throughout 2005 and early 2006.

Step 3. The Council 'Adopts' the Proposal for Framework 7

The process described in Step 2 will continue until the Council of Ministers are happy with the structure of the Framework 7 programme. This is a critical part of the process. The debate will end when the 'Council Adopts the Framework 7 Proposal'. This is the main power of the Council of Ministers (Figure 4). This is expected to happen in May 2006.

Step 4. The Commission 'Implements' Framework 7

At this point, the 'Proposal for Framework 7' will be returned to the European Commission (Figure 5). They will then use this document to design the detailed workprogrammes. Following this, 'Calls for Proposals' will be published. The preparation of the workprogrammes should be completed in late 2006 and the first 'Calls for Proposals' should be published in early 2007.

Discussions on Framework 7 (December 2004)

The Budget: Already a figure of €30 billion has been suggested (compared to a budget of €17.5 billion for Framework 6). This will be debated and decided on in early 2005. The proposal to date is that the programme should be divided into five main areas:

- Maintain Policy Driven Research (like Framework 6)
- Basic Research to be included with extra funding.
- 'Technology Platforms'
- Coordination of National Research Programmes (ERA-Net type activities)
- Development of Human Resources and Infrastructures

Basic Research in FP7

This is the most important new issue to date. In January 2004 the European Commission published a Communication entitled: Europe and Basic Research COM (2004) 9 of 14.1.2004 http://europa.eu.int/comm/research/press/2004/pdf/acte_en_version_final_15janv_04.pdf

In February 2004, an EU symposium on Basic Research was held in Dublin. The conclusions of this symposium recommended the inclusion of basic research in Framework 7. The conclusions of the symposium can be found on www.eu2004.ie/templates/news.asp?sNavlocator=66&list_id=271

This is the first time that a specific programme on Basic Research will be included in the Framework programme. The evaluation criteria will be 'Excellent Science' only. All of the other usual criteria (partners, deliverables, industrial involvement etc.) will not be used in the evaluation process.

Technology Platforms

This is the next new item on the agenda for Framework 7. The Commission has already launched 22 'Technology Platforms'. Details of these can be found on a special website on 'Technology Platforms' on www.cordis.lu/technology-platforms/. Examples of the platforms that have been launched are:

- Hydrogen and Fuel Cells Technology Platform (launched in 2004)
- Steel Technology Platform
- Water Supply and Sanitation Technology Platform (to be launched 2005)
- Mobile Communications and Technology Platform (part of European Growth Initiative)

How to Monitor and Participate in the debate on Framework 7

The following are the sources of information to follow the developments of FP7. All of these websites can be found on www.hyperion.ie/fp7websites.htm

How to Stay up to date with FP7

- **FP7 on Cordis:** Cordis has set up a website www.cordis.lu/fp7/

• **FP7 on Europa** (EU official website) http://europa.eu.int/comm/research/future/index_en.html
• Cordis News www.cordis.lu/news/ Any topics on Basic research, technology platforms, coordination of national programmes etc. will be published in Cordis News..
• **EURAB:** The European Research Advisory Board is a high level advisory group, consisting of 45 experts. They provide the commission with advice on the progress of FP6 and on future directions (FP7). Their reports can be found on http://europa.eu.int/comm/research/eurab/inded_en.html

How researchers can contribute to the debate on FP7

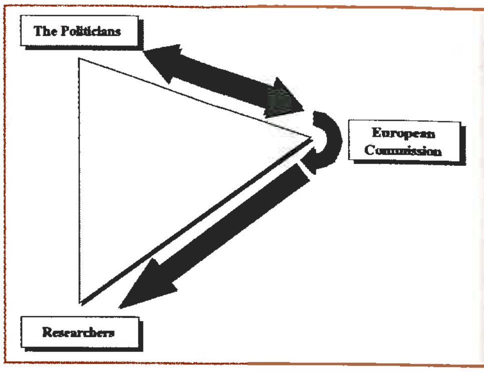
• **National inputs to FP7:** Every EU Member State will make a formal submission to the debate on FP7. These submissions will be based on information supplied by researchers. This is the best opportunity that scientists have to ensure that their research topic is not omitted from FP7. Examples can be seen on UK www.ost.gov.uk/ostinternational/fp7 • France http://eurosfaire.prd.fr/7pc/forum • Ireland www.forfas.ie/events/consultation.html
• **EU Conferences on FP7:** Researchers can contribute to FP7 through a number of special conferences that are organised as part of the EU Presidency. During the first six months of 2004 the presidency was held by Ireland www.eu2004.ie. During the last six months of 2004 the presidency was held by The Netherlands www.eu2004.nl.
• **Other Conferences contributing to FP7:** A range of conferences being organised to prepare submissions to FP7. These can be found on www.cordis.lu/news/.
• **Submissions by EU R&D Associations:** Most European Research Associations will make a formal submission to the debate on FP7. Examples of organisations that will make formal submissions (by sector) can be found on www.hyperion.ie/euassociations.htm
• **Preparatory Actions (FP6):** During FP6 the European Commission funded a number of projects to identify future topics for research. These were called Specific Support Actions and can be found on http://www.cordis.lu/fp6/projects.htm.
• **EAGS:** The European Commission has set up External Advisory Groups to act as external advisors for FP6. These experts are also used in the preparation of new programmes. They can be found on www.cordis.lu/fp6/eags.htm

Conclusion:

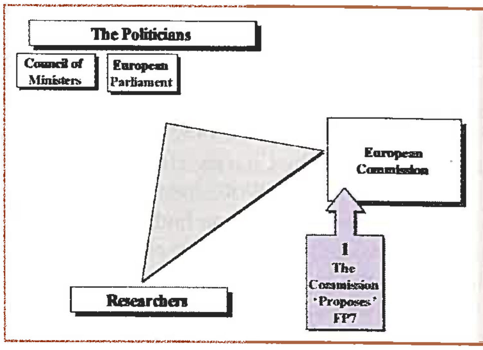
The preparation of Framework 7 is at full speed. For Research Managers, it is essential to be able to follow, and more importantly, to be part of the preparation of Framework 7. By following the development of Framework 7, research managers will be able to provide better advice to researchers on the background to the programme and on new evaluation criteria. The new directions that will be proposed for Framework 7 will be tested during the Framework 6 programme. This is an important consideration, especially for research proposals that will be submitted towards the end of the Framework 6 programme (2005 and 2006). For the New Member States, the development of Framework 7 is a good opportunity to monitor and learn the decision making process of the European Union.

About the author

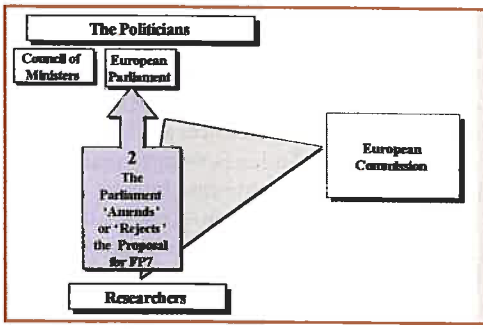
Dr. Sean McCarthy (sean.mccarthy@hyperion.ie) is Managing Director of Hyperion Ltd. Hyperion specialises in the development of training course for research managers. Full details of their training courses can be found on www.hyperion.ie. Hyperion's clients can be seen on www.hyperion.ie/clients.htm



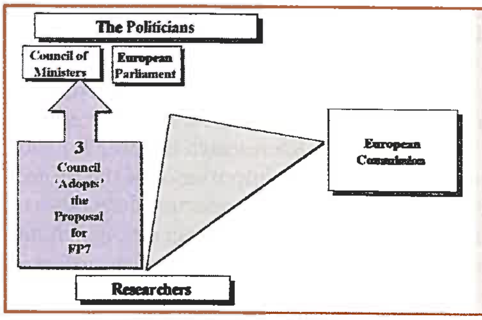
◄ **Fig. 1:** How FP7 will be prepared



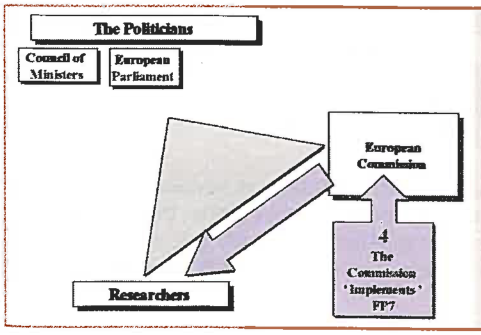
◄ **Fig. 2:** The Commission 'Proposes' FP7



◄ **Fig. 3:** The European Parliament is 'Consulted'



◄ **Fig. 4:** The Council 'Adopts' the Proposal



◄ **Fig. 5:** The Commission 'Implements' FP7

HiSPARC

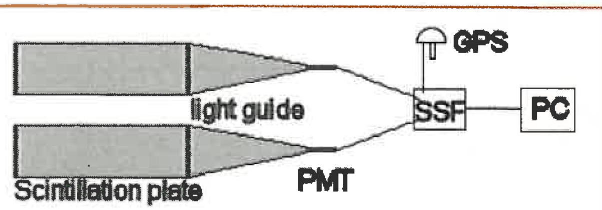
Pierre van Baal (Leiden University) and Jan-Willem van Holten (NIKHEF, Amsterdam), for the HiSPARC collaboration.

Science education is of great cultural and economic importance for modern societies. It is also of great importance to science itself, as scientific continuity depends on our success in educating and training the next generation of scientists and science teachers. To be successful, science education must challenge the intellect and captivate the mind of young people, and acquaint them with the joy of discovery and understanding.

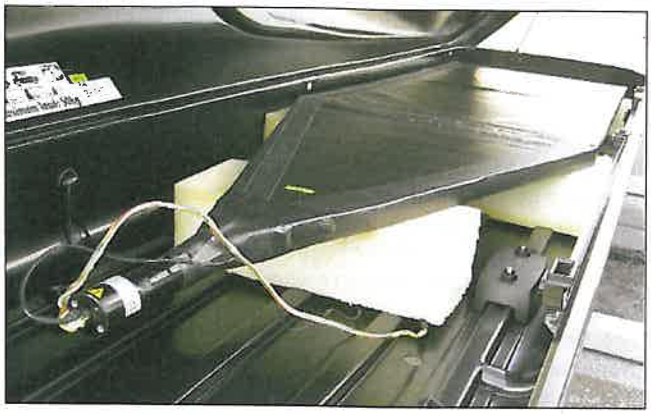
There is no better way to achieve this than by involving students in research as early as possible. This is the main aim of the High-School Project on Astrophyics Research with Cosmics (HiSPARC) [1]. Following the example set by others elsewhere [2] and initiated in the Netherlands by Charles Timmermans and Sijbrand de Jong in Nijmegen [3], HiSPARC members have built a network of cosmic-ray detectors based on high-school infrastructure, involving students and teachers in an essential way by making them collaborators in the research.

A cosmic ray is observed through the shower of secondary particles it creates when entering the atmosphere of the earth. The larger the area the shower covers when reaching the surface, the larger the primary energy of the cosmic particle. Such showers are reconstructed through coincidence measurements between detectors. These detectors are placed on the roof of the participating schools, creating city-centered regional clusters of detectors. The average distance between the schools guarantees a sufficient number of coincidences, allowing students to get meaningful measurements within a period of a few months. Internet connections, available at all schools in the Netherlands, allow the transfer and central collection of data. Subsequently data and suitable analysis tools are made available to all participants. At the same time, the involvement of enough schools provides an opportunity to hunt for Ultra-High Energy Cosmic Rays (UHECRs). In this way the project can contribute to solving the puzzles surrounding the origin and nature of these cosmic particles with energies above 10^{20} eV.

At the initiative of Bob van Eijk, Henk-Jan Bulten and the present authors the project is now run at a national level. It is co-ordinated by NIKHEF, the Dutch research institute for subatomic physics in Amsterdam. The importance of the project was recognized by the Foundation for Fundamental Research of Matter (FOM), a national physics funding agency, which has appointed Ilka Tanczos as full-time national project co-ordinator.



▲ Fig. 1: Indicated are schematically the scintillation plates, light guides, the Photo Multilier Tubes (PMTs), the Scintillator Signal Follower (SSF), the Global Positioning System (GPS) antenna to provide a time-stamp and the PC for data acquisition.



▲ Fig. 2: Ski box containing one unit of the detector.

Recently HiSPARC also received a strong boost when it was awarded the prestigious european 2004 Altran Prize for Innovation [4]. The Altran Foundation will provide a full year of technical support and assist in the development of a professional organization. Nationwide the project now has five active detector clusters in Amsterdam, Groningen, Leiden, Nijmegen and Utrecht.

An important part of the fun is that high-school students of each participating school get to build, calibrate and maintain their own detector. This includes wrapping the scintillator plate and light guide in reflecting aluminum foil to minimize the loss of photons produced in the scintillator by charged particles that are part of a cosmic air shower, and covering the plates with light-tight plastic foil to keep out light from other sources. The students then have to glue the scintillator plate, light-guide and photo multiplier tube (PMT) together and calibrate the final detector. In this way they learn to work in a team, they find out that doing research involves learning from failure and mistakes, and they get to know the excitement that goes with potential discoveries. Indeed, a very stimulating factor for them is the anticipation that this project may provide new scientific results, even if this requires many years of data taking.

Each detector station consists of two scintillator plates, placed several meters apart in ski boxes to keep them safe and dry. A GPS antenna provides a time stamp for registered events. Only events producing a signal in both detectors within a couple of microseconds are stored on a central computer (presently there are two, one in Nijmegen and one in Amsterdam). High-school students and teachers have access to these data. The data can be analysed for coincidences between schools in the same area, or for correlations with atmospheric conditions, but one can also search for clustering of different events over a larger area. Starting only this summer the Nijmegen cluster has already observed quite a number of triple coincidences. Such measurements allow by triangulation the determination of the direction of the primary cosmic particle creating the airshower.

An interesting aspect of the set-up in Leiden is that the HiSPARC detector recently installed at the university is also intended to function as a veto for excitations in the miniGRAIL gravitational wave detector [5] simultaneous with the arrival of a cosmic air shower. Clearly HiSPARC is a near unlimited source of research projects, which are a compulsory part of high-school science education in the Netherlands.

HiSPARC is still young, but it has already built up considerable momentum. It should run for at least ten years, and a considerable effort is going into the development of educational packages, mostly by teachers of the participating schools. Several of them receive funding to allow their schools to temporarily free them for work on HiSPARC, typically for one day per week. All this helps in fulfilling the goals of science education: stimulate teachers and students to enjoy science in a active way, and bring scientific thinking and scientific culture into the schools.

▲ **Fig. 3:** Typical arrangement of the detector on the roof of a school.

References

[1] The national HiSPARC webpage: www.hisparc.nl

[2] The NALTA webpage: csr.phys.ualberta.ca/nalta/

[3] The Nijmegen HiSPARC webpage: www.hef.kun.nl/nahsa/

[4] The Altran Foundation webpage: fonda.netarchitects-europe.com/

[5] Poster presented at the 19th Cosmic Ray Symposium in Florence: www.lorentz.leidenuniv.nl/vanbaal/HiSPARC-MiniGRAIL.pdf (2.3 Mb); The MiniGRAIL wepage: www.minigrail.nl

Old ears

L.F.J Hermans, Leiden University, The Netherlands

If you are under, say, 35, you might as well stop reading: you should have no reason to worry about your ears. But for many of us who are somewhat older, a noticeable hearing loss may become a bit cumbersome every now and then. And as it turns out the loss is worst where it hurts most: in the high frequency regime.

Let us first look at the data. In the figure, hearing loss data are given as a function of frequency for a large sample of people at various ages (Courtesy: Dr. Jan de Laat, Leiden University Medical Center). And indeed, already at age 60, the loss of high-frequency tones is frightening: over 35 dB at 8 kHz, increasing about 10 dB for every 5 years of age. Once we're 80, we'll be practically deaf for 8 kHz and up.

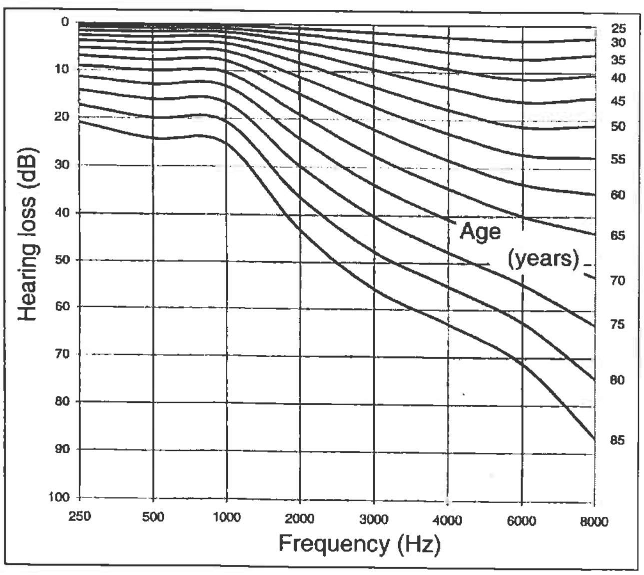
Why is hearing loss at the higher frequencies so bad? When listening to our stereo at home, we can turn up the treble a bit for compensation, no problem. And in a person to person conversation, we don't really have problems either. That is until we are having a conversation at some cocktail party. Then we notice: the background noise makes things worse.

One aspect playing a role here concerns consonants like p, t, k, f and s. They contain mainly high-frequency information, and will therefore easily be masked, or will become mixed up. Another aspect relates to the role of sound localization in selecting one conversation out of a background noise (sometimes referred to as the 'cocktail party effect'). We are pretty good at localizing sound: up to 1-2o in the forward direction (see William M. Hartmann in Physics Today, November 1999, p. 24 ff).

We use two mechanisms to do that. First, by using the phase- or arrival time difference between the two ears: the Interaural Time Difference (ITD). Of course, the information is unambiguous only if the wave length is large compared to the distance between our ears. It is therefore effective only at the lower frequencies, say, below 1,5 kHz. However, in ordinary rooms and halls, reflected sound often dominates, especially for low frequencies. This is because the acoustical absorption decreases with decreasing frequency for almost all reflecting surfaces. As a result, the ITD becomes unreliable in such situations, and the low frequencies are not much of a help to spatially isolate one conversation from the noise.

Fortunately, we have a second mechanism, which uses the intensity difference between the two ears for sound coming from aside: the Interaural Level Difference (ILD). We remember that sound waves become effectively diffracted when their wavelength is much shorter than our head: the head casts a shadow, so to speak. Therefore, ILD works well above, say, 3 kHz.

Alas, look at the graph: the high-frequency region is where old ears have problems. So the ILD doesn't work too well either. In the end, we may have to resort to what deaf people do all along: use our eyes, and see the talking....



Prize Winners Gross, Politzer and Wilczek

Per Osland [1] and Julius Wess [2],
[1] University of Bergen, Allegaten 55, N-5007 Bergen
[2] University of Munich, Theresienstr. 37, D-80333 Munich

The 2004 Nobel Physics Prize has been awarded to David J. Gross, H. David Politzer, and Frank Wilczek for their seminal work on Quantum Chromodynamics, the theory of strong interactions. It follows their award of the 2003 EPS High Energy and Particle Physics Prize. In both cases, the citation is almost identical: the Nobel citation reads: "for the discovery of asymptotic freedom in the theory of the strong interaction" whereas the EPS citation reads: "for fundamental contributions to Quantum Chromodynamics, demonstrating asymptotic freedom". It is not the first time the EPS Prize has been followed by a Nobel Prize.

▲ D. Gross, D. Politzer and F. Wilczek

Early history

In the early 1970s, there was an emerging understanding of weak interactions [1] in terms of a nonabelian renormalizable gauge theory [2]. In strong interactions there was a beginning of a classification of hadrons in terms of the quark model [3], but free quarks had never been seen and their bound states, the hadrons, were in conflict with the Dirac statistics of quarks [4]. This posed a problem in accepting quarks as physical realities.

The breakthrough in the understanding of the strong interaction in terms of Quantum Chromodynamics -QCD- a nonabelian gauge theory for quarks and gluons proposed by Fritzsch and Gell-Mann came in several steps. There was the experimental discovery at SLAC of scaling in deep inelastic scattering by Friedman, Kendall, Taylor and collaborators [5], and the deeper theoretical understanding of renormalization, in particular via the renormalization group approach pioneered by Callan, Symanzik and Wilson, and finally by the work of Gross, Politzer and Wilczek [6,7].

The scaling observed in the scattering of electrons on protons at SLAC, was described by Bjorken and Feynman in terms of the scattering from nucleon constituents that were essentially free. Could these constituents be the quarks of Gell-Mann and Zweig? This was in conflict with the fact that quarks had not been observed even in the most energetic interactions.

Theoretical studies of renormalizable field theories such as Quantum Electrodynamics and ϕ^4 theory had revealed that the coupling constant (the β-function) was an increasing function of energy or momentum transfer. This was believed to be a general feature, and would thus be in conflict with the SLAC data.

In their basic papers published in 1973 Gross, Politzer and Wilczek showed that the situation might change for nonabelian gauge theories. These theories have the remarkable property that the β-function might also decrease with energy, leading to asymptotic freedom. For SU(3), their result can be written as

$$\beta(g^2)=\mu(dg/d\mu)=-(g^3/16\pi^2)\ [11-(2/3)N_f],$$

where μ is the momentum-transfer scale, and N_f is the number of fermions in the theory. The fact that (for Nf not too large) $\beta(g^2)<0$, means that *the coupling gets weaker as the energy or momentum transfer grows*. This is *contrary to the case of QED*, where vacuum fluctuations tend to screen the charge, and make it appear smaller when probed at small momentum transfers.

This result is remarkable because: (1) it is an entirely new concept, specific to nonabelian theories, and (2) it made it possible to calculate physical quantities in the limit of large momentum transfers. A perturbation expansion was thus available for the strong interactions that could be compared to experiments.

By demonstrating that the theory based on SU(3) is asymptotically free, that the coupling becomes weak at large momentum transfers, Gross, Politzer and Wilczek paved the way for showing that QCD might be correct. Shortly after their papers were published, it became clear that this new theory is capable of explaining the strong interactions [8,9]. This opened an entirely new era in particle physics. [For an account of the early history of QCD and asymptotic freedom, see the contributions by 't Hooft and Gross in [10].]

Implications

On the basis of the results by Gross, Politzer and Wilczek, it immediately became clear that vast sectors of the strong interaction could be described perturbatively with a considerable precision, and could be systematically and meaningfully compared with the experimental data.

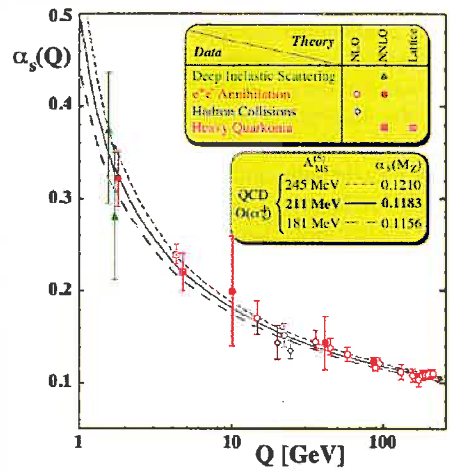
The calculability of a large class of observables, which turned out to be in agreement with the experimental data immediately gave strong attention to the theory.

By now, QCD has been accepted as the correct theory of strong interactions. This is based on a considerable amount of experimental data of different kinds. The early evidence came from scaling, the narrow J/ψ states and the study of deviations from scaling in the inelastic scattering of electrons, muons and neutrinos from nucleons. These deviations, which could be calculated in terms of the logarithm of the momentum transfer involved, turned out to be in good agreement with experiment.

Another, important line of evidence came from the discovery of gluon Bremsstrahlung at DESY in 1979 (for which the 1995 EPS Prize was awarded to Söding, Wiik, Wolf, and Wu) at a rate and with properties as predicted by the theory. Later, jet cross sections known to non-trivial order made possible the identification of the top quark at Fermilab in 1995.

Many aspects of QCD have now been investigated quantitatively, in particular at LEP and at HERA, DESY, where the proton structure is currently being investigated in great detail in terms of well-defined, QCD-based structure functions. The variation of the strong coupling with momentum scale is well established, and is in beautiful agreement with the theory (see Figure 1).

To explain the absence of free quarks the concept of confinement had been invented. Quarks remain confined at all energies.



◄ **Fig. 1:** Variation (running) of $\alpha=g^2/4\pi$ with momentum scale Q [11].

This property of QCD is not yet rigorously proven but strong evidence comes from lattice gauge theory as well as from the monopole description developed by 't Hooft. ■

About the prize winners

David Gross received his Ph.D. at Berkeley in 1966. He is director of the Kavli Institute for Theoretical Physics, Santa Barbara, CA, USA, and Frederick W. Gluck professor at the University of California, Santa Barbara, CA, USA. Apart from his work on QCD, he has made important contributions to the development of string theory. David Gross was awarded the 1986 Sakurai Prize of the American Physical Society, the 1988 Dirac Medal of UNESCO/ICTP, and the 2003 EPS-HEPP Prize.

David Politzer received his Ph.D. at Harvard in 1974. He is Professor of Physics at California Institute of Technology, Pasadena, CA, USA. After his early work on QCD, he has made important contributions to the theory of cold atoms and Bose condensation. David Politzer was awarded the 1986 Sakurai Prize of the American Physical Society, and the 2003 EPS-HEPP Prize.

Frank Wilczek obtained his Ph.D. at Princeton in 1974. He is the Herman Feshbach Professor of Physics at Massachusetts Institute of Technology, MA, USA. He has worked on a wide range of topics in QCD and made important contributions to the theory of particle statistics and cosmology. Frank Wilczek was awarded the 1986 Sakurai Prize and the 2003 Lilienfeld Prize, both of the American Physical Society, the 1994 Dirac Medal of UNESCO/ICTP, the 2002 Lorentz Medal, and the 2003 EPS-HEPP Prize.

About the authors

Per Osland is a professor of physics at the University of Bergen. He has worked on phenomenology related to QCD, electroweak interactions, and neutrino physics.

Julius Wess is an emeritus professor of physics at the University of Munich, LMU, and the Max Planck Institute for Physics, Munich.He has worked on particle physics and quantum field theory.

References

[1] S. L. Glashow, Partial Symmetries Of Weak Interactions, Nucl. Phys. 22, 579 (1961); S. Weinberg, A Model Of Leptons, Phys. Rev. Lett. 19, 1264 (1967); A. Salam, in Elementary Particle Theory: Relativistic Groups and Analyticity (Nobel Symposium No. 8), edited by N. Svartholm (Almqvist and Wiksell, Stockholm, 1968), p. 367; S. L. Glashow, J. Iliopoulos and L. Maiani, Weak Interactions With Lepton - Hadron Symmetry, Phys. Rev. D 2, 1285 (1970).

[2] C. N. Yang and R. L. Mills, Conservation Of Isotopic Spin And Isotopic Gauge Invariance, Phys. Rev. 96 (1954) 191.

[3] M. Gell-Mann, A Schematic Model Of Baryons And Mesons, Phys. Lett. 8 (1964) 214; G. Zweig, An SU(3) Model For Strong Interaction Symmetry And Its Breaking. 2, CERN-TH-412.

[4] O. W. Greenberg, Spin And Unitary Spin Independence In A Paraquark Model Of Baryons And Mesons, Phys. Rev. Lett. 13 (1964) 598; M. Y. Han and Y. Nambu, Three-Triplet Model With Double SU(3) Symmetry, Phys. Rev. 139 (1965) B1006.

[5] M. Breidenbach et al., Observed Behavior Of Highly Inelastic Electron - Proton Scattering, Phys. Rev. Lett. 23 (1969) 935.

[6] D. J. Gross and F. Wilczek, Ultraviolet Behavior Of Non-Abelian Gauge Theories, Phys. Rev. Lett. 30 (1973) 1343

[7] H. D. Politzer, Reliable Perturbative Results For Strong Interactions?, Phys. Rev. Lett. 30 (1973) 1346.

[8] S. Weinberg, Nonabelian Gauge Theories Of The Strong Interactions, Phys. Rev. Lett. 31 (1973) 494.

[9] H. Fritzsch, Murray Gell-Mann, H. Leutwyler, Advantages Of The Color Octet Gluon Picture, Phys. Lett. B 47 (1973) 365.

[10] The Rise of the Standard Model, Particle Physics in the 1960s and 1970s, edited by L. Hoddeson, L. Brown, M. Riordan, M. Dresden, Cambridge University Press, 1997. See also articles by G. 't Hooft and D. J. Gross in Proceedings from 25 Years of Quantum Chromodynamics, Nucl. Phys. B (Proc. Suppl.) 74 (1999).

[11] S. Bethke, alpha(s) 2002, Presented at QCD 02: High-Energy Physics International Conference in Quantum Chromodynamics, Montpellier, France, 2-9 July 2002; hep-ex/0211012.

EPS-EPCS Prize 2005

The EPS-EPCS Board is calling for nominations for the fourth EPS-EPCS biennial prize, which will be conferred during ICALEPCS 2005, the "International Conference on Accelerators and Large Experimental Physics Control Systems", Geneva, 10-15 October 2005. The prize is awarded to one or more young scientists for outstanding achievement in the field of Experimental Physics control systems. It consists of a certificate and a financial contribution of 2000 Euro. Prize regulations are available at http://epcs.web.cern.ch/epcs/Statutes/Prize.html.

Valid nominations include a CV of the candidate, a description of his/her past and current activities in the field of controls together with his/her most significant publications. They should be sent through an EPS-EPCS Official Contact Person (see http://epcs.web.cern.ch/epcs/People/OfficialContact-Delegates.html) before April 22nd, 2005 to:

Daniele Bulfone
Sincrotrone Trieste
S.S.14 - Km.163.5 in Area Science Park
I - 34012 Trieste, Italy
tel.: +39 040 3758579 • fax.: +39 040 3758565
e-mail: daniele.bulfone@elettra.trieste.it

Related links:

EPS-EPCS home page: http://epcs.web.cern.ch/epcs/
ICALEPCS home page: www.icalepcs.org

news & views

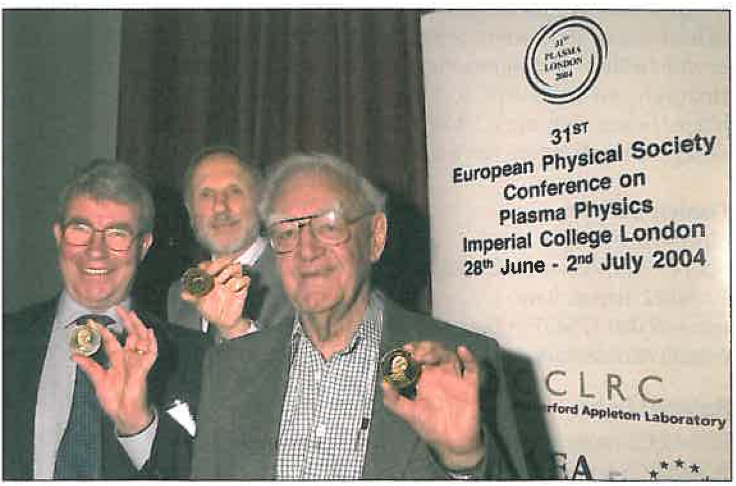
Plasma Physics Division Hannes Alfven Prize

For their seminal contributions to a wide range of issues of fundamental importance to the success of magnetic confinement fusion, including: development of gyro-kinetic theory; prediction of the bootstrap current; dimensionless scaling laws; pressure-limiting instabilities, and micro-stability and transport theory.

Laudation for J W Connor, R J Hastie and J B Taylor

Jack Connor, Jim Hastie and Bryan Taylor form one of the most successful teams of theoretical physicists in the history of magnetic confinement fusion. They have made important contributions individually, but their greatest discoveries were mostly accomplished jointly, either in pairs or as a team involving all three of them. Their early work, in the 1960's, included the development of gyro-kinetic theory for fine-scale plasma instabilities, which today forms the basis of the most advanced turbulence simulation codes in tokamak and stellarator research. The theoretical prediction of the bootstrap current, made in 1970-71, was not confirmed experimentally for over a decade but is now regarded as crucial to the success of the tokamak as a steady-state fusion power source. Their work on collisional transport also included the prediction of impurity-ion accumulation, which is observed in internal transport barriers and is a key concern for long-pulse tokamak operation. The relativistic threshold for runaway electrons, identified in 1975, forms the basis of the most recent tokamak disruption mitigation schemes. In the late 70's, the team developed the theory for ballooning instabilities, which provided an important ingredient in the "Troyon-Sykes" β-limit – an expression that is still used as a guide to the performance of tokamaks and in design of ITER. Ballooning-mode theory has also contributed to the understanding of instabilities in space plasmas such as magnetospheres and the solar corona. Finally, coming right up to date, the ballooning mode is thought to be a key ingredient in edge-localised modes (ELMs), which are a main issue for ITER, and ballooning stability is an important feature of modern stellarators. In the late 1970's and through the 80's, the concept of dimensionless scaling laws was introduced and developed (following work by Kadomtsev), enabling scalings for transport coefficents to be derived without tackling all the details of the plasma turbulence. The same ideas are still used today to provide various constraints on confinement scaling laws, for example, on which the ITER design is largely based. The linear theory of toroidal drift waves was also developed by the team during this period, and into the 90's. Key results on the role of shear damping in toroidal geometry, the identification of modes with extended radial correlation lengths, and the role of flow shear in reducing these correlation lengths (and hence transport) were deduced. All of these are key ideas that are often components in theoretical models for tokamak confinement and the generation of transport barriers.

This laudation can only address a small number of the areas in which this formidable team of theoretical plasma physicists have made great contributions to our understanding of magnetically confined plasmas. It is appropriate and timely that their contributions are recognised as they approach the end of their careers. ■



◄ J.W. Connor, R.J. Hastie and J.B. Taylor

Lise Meitner Prize for Nuclear Science 2004

The European Physical Society (EPS) has awarded the Lise Meitner Prize for Nuclear Science 2004 to Professor Bent Herskind (Niels Bohr Institute, Copenhagen, Denmark) and Professor Peter Twin (University of Liverpool, UK) for their pioneering development of experimental tools, methods of analysis and experimental discoveries concerning rapidly spinning nuclei, resulting in particular in the discovery of super-deformed bands.

The Physics Case:

In the study of atomic nuclei, the connection between shell structure and symmetry has been a central theme. In quantum theory the appearance of a rotational mode requires a deviation of the quantum state from rotational symmetry (deformation). If the nuclear excitation energy is concentrated in collective rotational motion the temperature is very low, the internal structure is governed by quantal effects and is well ordered. To produce such highly excited but cold nuclei with high spins in a nuclear collision the reaction mechanism has to be carefully chosen. States at high spin are created through nuclear reactions between carefully chosen heavy ions that fuse and decay to produce the required species. In the process huge numbers of gamma-rays corresponding to transitions which have nothing to do with the states of interest are produced. The challenge is to identify the relevant gamma-rays from this abundance.

One of the surprising experimental discoveries of the 1980's was that nuclei can accommodate a surprisingly large amount of excitation energy in a simple rotational motion when they are created in particular configurations. These configurations are called super-deformed states because then the nucleus has a shape like a rugby ball with its long axis twice as long as its short axis. The possibility of stable configurations with super deformation in nuclei was first proposed in the 1960's as an interpretation of isomeric states observed in actinide nuclei which decay by spontaneous fission. The associated shell-structure arises due the bunching of single-particle levels in the average binding potential, and leads to an understanding of the stabilisation of such configurations. It was later realized that because of their large moments of inertia super-deformed states could become the states of lowest energy for a given high spin in many other nuclei. The signatures of super-deformed bands are unusually large moments of inertia and strong collectivity in electromagnetic decays, both of which can be pinned down by measuring gamma rays. B. Herskind and P. Twin were pioneers and key contributors to the development of 4π-detector systems consisting of a very large number of γ – detectors. In particular, they contributed to the analysis of emitted gamma rays that identify these novel shapes. In 1986 a band of 19 discrete lines was observed by P. Twin et al., in 152Dy. The associated gamma-ray lifetimes were so short that the only natural explanation was that the states involved were super deformed. Within a few years many super-deformed bands were identified in other mass regions. Today, super-deformed rotational bands have been discovered all over the nuclear chart.

For the study of the detailed structure of nuclei at high spins the development of large arrays of high-efficiency, high-resolution multi-detector arrays was crucial. In Europe B.Herskind played a leading role in this field. Furthermore, B. Herskind and P. Twin were the leaders in the introduction of escape-suppressed detectors for detecting gamma-rays in a coincidence setup. The continued development of these detector systems in Europe led to the TESSA array in Britain. The detector array TESSA2, which led to the discovery of super deformation by P. Twin was built at Daresbury Laboratory (UK), in collaboration with British and Nordic groups from Copenhagen and Stockholm. This paved the way for more advanced detector systems like EUROBALL (see recent article in Europhysics News, 2003 Sept/Oct) and the future European project AGATA. The HERA detector systems were a parallel development by F. Stephens at Berkeley, USA.

The development of the large arrays of Compton suppressed γ-detectors has opened up a new exciting area of nuclear physics and has had an enormous impact on the whole field of nuclear structure physics. Through the outstanding achievements of B. Herskind and P. Twin, European nuclear structure physics has attained a frontline position in the scientific world and has initiated the creation of many new multi-detector arrays throughout the world. (see also homepage at www.kvi.nl/~eps_np/) ■

Forum of European Condensed Matter Physics in Prague

J.T. Devreese, Univeriteit Antwerpen, Belgium

The 20th General Conference of the Condensed Matter Physics of the European Physical Society was held in Prague on 19-23 July 2004. The organisers of the Conference, which was chaired by Prof. Vladimir Sechovsky, provided the unforgettable creative atmosphere. The conference in Prague, like the previous ones, was organized in the felicitous format of plenary sessions, focused sessions with invited speakers, minicolloquia and poster sessions. The scientific program of the 20th General Conference, which was carefully selected by the International Programme Committee under the chairmanship of Prof. Bedrich Velicky, reflected a broad scope of investigations on the forefront of the modern Condensed Matter Physics, i.e. in nanoscience, materials science, magnetism, low-dimensional systems and interdisciplinary fields.

Of particular interest were the lectures by the Nobel Prize 2003 laureate A. J. Leggett about the fascinating development of conceptual issues in the field of superfluidity and by the Agilent Technologies Europhysics Prize 2004 winners M. Devoret, D. Esteve, H. Mooij, Y. Nakamura on the recent progress and amazing perspectives of the superconducting quantum bit circuits (the lecture was presented by D. Esteve). The related problems of quantum computing were discussed also at the focussed fessions and minicolloquia on quantum dots for quantum computing, electron entanglement and Bell inequalities in solid-state systems, superconducting qubits, quantum computing and decoherence (in particular, by H. Mooij).

Nanophysics was one of the key issues, reviewed in the plenary talks "Quantum Dot Nanostructures: Paradigm Changes in Semiconductor Physics" by D. Bimberg and "Nanomechanical Systems" by M. Roukes and discussed at the sessions on electron dephasing in mesoscopic systems, single photon solid-state sources, mesoscopics, physics of nanomaterials, metal nanoparticles, nanotubes, structural studies of low-dimensional nanosystems, hybrid biogenic and inorganic nanostructures and others.

In his plenary talk A. Fert dealt with an intensively developing field of spintronics, which was also the subject of the sessions on ferromagnetic semiconductor materials and spintronic devices, spin polarized transport and others.

New physics of atomic gases was presented in the overview provided by A. J. Leggett, in the plenary talk dedicated to exploring quantum matter in optical lattice potentials by I. Bloch, at the Focused Sessions on New Frontiers in Bose-Einstein Condensation and Minicolloquium Novel phenomena in atomic quantum gases.

The plenary talk "Novel magnetic semiconductors" by T. Dietl and the sessions on physics of f-electron materials, p-wave pairing in metals, HTSC physics, ferromagnetic superconductors, dilute magnetic semiconductors, quantum criticality 2D and 3D correlated electron systems, structure and dynamics of disordered ferroelectrics and others were dedicated to the physics of new materials.

Modern theoretical approaches were presented throughout a majority of sessions, in particular, in the plenary talk "Bridging the Electronic to Atomistic Modeling Hierarchies" by D. Pettifor and in the Focuses Sessions and Minicolloquia on the theory of optical and dielectric properties in condensed matter, a dynamical mean field theory for real materials, molecular dynamics studies of surface processes and others.

Particular attention was paid to advanced experimental studies in the plenary talks on superfluid-like behaviour in solid He-4 and Casimir forces in liquid helium films by M. Chan and in the Focused Sessions on nanoscience and soft condensed matter at large facilities, development from femto- towards attosecond timescale in solids, manipulations at surfaces, interaction of matter with laser light under extreme conditions, ultrafast spectroscopy, slow and fast light...

We would like to take this opportunity to thank the organisers, especially V. Sechovsky and B. Velicky, as well as the EPS Condensed Matter Division for another excellent conference. All in all, the EPS CMD20 conference has been an exciting and stimulating meeting, vibrant with new results and ideas. ■

Entente Cordiale Scientifique à Paris

D. Weaire, Trinity College, Dublin

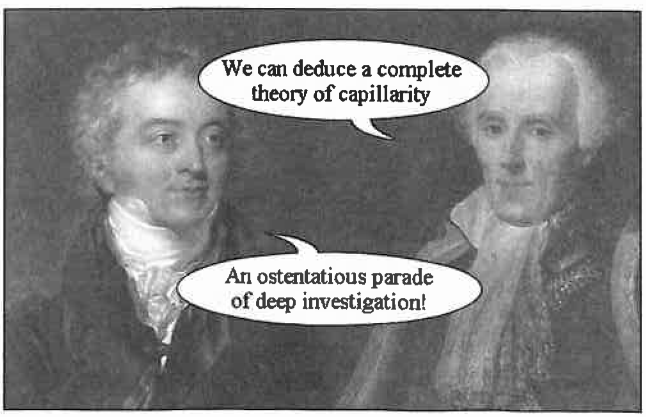
On September 17 the Ecole Superieure de Physique et Chimie Industrielle in Paris played host to a new kind of conference, under the above title. History of physics and related outreach activities were discussed from French/British (and Irish) perspectives. The EPS and the IOP supported the meeting through their relevant committees, so there was broad international participation.

Its success heralds a continuing series of Anglo-French encounters, of which the next is already pencilled in for late 2005 or early 2006, It will be centred on the *contretemps* between Laplace and Young over precedence in the theory of capillarity, an outstanding example of the diverging tastes and tendencies of the two scientific communities.

The EPS is also planning a meeting in London on the theme of early Portuguese interactions with the Royal Society.[See article by C. Fiolhais in EPN 34/4, p154]

The Paris meeting began with authoritative reviews of the history and status of science museums from Etienne Guyon and Neil Brown. The French tradition is rich and varied, but Guyon argued that no more great museums should be founded. The new eara will see more travelling or virtual exhibits and small outreach centres. An excellent new example is to be seen at the ESCPI itself, where the original experiment of the Curies is being reinacted in a new *espace des sciences*. A talk by P.Radvanyi presented the respective role of the husbands and wifes in the career of the Curies and the Joliot Curie. We were reminded that radioactivity was first detected by Becquerel, just down the road in the Jardin des Plantes. This urgently needs to be recognised and marked in appropriate ways. In a similar vein, D Thoulouze , director of the renewed Conservatoire des Arts et Metiers, spoke of the demanding imperative of conservation of recent scientific equipment- but what should we keep, and where should we put it? Nobody seemed to have an immediate answer.

Another recurrent question asks how (and how much) history we should incorporate in our mainstream lecture courses. J.Treiner addressed this, and as an example gave a geometrical description of the second Kepler law following an approach of Newton and Hooke, in terms of finite differences. He compared its merits with those of the Eulerian differential description.



Another session dealt with two significant figures in 20th century physics in France. M.Coey recounted the remarkable achievements of Louis Neel, not just as a great physicist, but also as a farsighted administrator and planner to whom the city of Grenoble must owe a great debt. R.Cahn told of a more obscure figure of French science, though he won the Nobel Prize in the year before Einstein. This was C.E.Guillaume, the inventor of invar alloy.

Appropriately, many participants spent Sunday afternoon at the Palais de la Découverte. Indeed the *entente* was *cordiale*! ■

EPS members who have suggestions for future meetings or wish to play an active role in history of physics are encouraged to contact the secretary:

George Vlahakis <gvlahakis@yahoo.com>

The committee itself is currently being renewed. Its next meeting is planned for May 2005.

Seven Years - Seven Domiciles. Albert Einstein's Bernese Period

Ann M. Hentschel, University of Bern.
www.einstein2005.ch

In February 1902, a 22-year old graduate of the Federal Polytechnic in Zurich arrived at the Bern train station with little more in his luggage than a teacher's certificate. After his first attempt at a doctorate at the University of Zurich had failed, Albert Einstein decided to seek his fortune in the Swiss capital. His furnished bachelor's lodgings at Gerechtigkeitsgasse 32 was situated on one of the main shopping streets of the old town. There he welcomed his first Bernese pupils to respond to his advertisement for private tutoring in physics and mathematics. One of them was the Rumanian student of philosophy, Maurice Solovine, who remembered having to grope his way up two dingy flights for his free trial lesson. Their mutual interest in philosophy quickly turned into a lasting friendship. They met regularly to discuss the classics in philosophy and the natural sciences over sausage, gruyère and a few cups of tea. Conrad Habicht, a doctoral student of mathematics with like interests in natural philosophy and music joined their evening sessions, which they jocularly referred to as their 'Olympia Academy'. Many of the texts they discussed broached topics of relevance to Einstein's later considerations on space-time.

Einstein's initial hopes of obtaining a position at the Swiss Federal Patent Office as an examiner finally came to fruition in June 1902. The patent applications that landed on the desk of the young 'Provisional Technical Expert, 3rd class' in the first decade of the 20th century included engine designs as well as applications

▲ Fig. 1: The main building of the University of Bern, built 1903

As part of the jubilee festivities in Bern in celebration of the centennial of special relativity and Einstein's light quantum hypothesis, the University and the City of Bern are sponsoring a new walking trail past all of Albert Einstein's old haunts. It will follow the many traces left throughout the city by its world-famous resident between 1902 and 1909. Important stages in Einstein's life and work during his Bernese period are reviewed in about twenty signposted stops for the interested tourist to view peripatetically. The accompanying illustrated guidebook provides further historical details, source information, and historical and current photographs.

The guidebook **Albert Einstein: "Those Happy Bernese Years"** by Ann M. Hentschel and Gerd Grasshoff (Bern 2005) covers the following topics:

- life in Bern around the turn of the century
- Einstein at the Swiss Patent Office (contribution by Karl Wolf gang Graff)
- scientific influences (university - the local Naturforschende Gesellschaft - Olympia Academy)
- personal influences (family - friends - private pupils - teachers - colleagues)
- politics (e.g., Swiss democracy - workers movement - nationalism)
- social norms (e.g., pacifism - individualism - adoption)
- philosophy (Hume - Mach - Poincaré - Duhem)
- religion (Judaism - skepticism)

from the flowering electrical and transportation industries. Two months earlier, Einstein had moved away from the old city, nestled in a narrow meander of the river Aar, to a suburb on its southern shore. Thunstrasse 43a was on a busy thoroughfare and the newly electrified tramway passed right by his doorstep. That lease was of short duration. Einstein moved a few blocks westward to Archivstrasse 8, a quieter street in the Kirchenfeld district, rooming in an attic. From its balcony the young man enjoyed a resplendent view of the new parliament building across the sparkling glacial river, with the snow-capped Bernese alps ranged on his left. With his trial period safely behind him, Einstein formally tied the knot with his former Serbian classmate in Zurich Mileva Marić in January 1903 and they set up house a couple of blocks further south at Tillierstrasse18 - their "ménage of paradise," as Einstein called it. The busy civil servant still found time to join the local scientific society, the Naturforschende Gesellschaft, which met every fortnight in the old town for presentations and talks encompassing the full range of the natural sciences. Its diverse membership included school teachers and university faculty.

The almost rural setting in Kirchenfeld may well have been too sleepy for the recent metropolitans. In October the Einsteins moved to a three-room apartment on Kramgasse, along the same arcaded axis of the old town as Einstein's first bachelor's logdings. Now the patent examiner only had a short walk to work every day. Passing by five ornate wells dating from the 16th century, he went under the archways of Bern's historic clock and prison towers, by the door of his colleague Michele Besso, and into one of the streets leading to the former Anatomiegasse, where the Patent Office was located until 1907 in the imposing new telegraph building. Besides the birth of his son Hans Albert in May 1904, this period in Kramgasse produced the famous paper on the light quantum as well as on Brownian motion. In May 1905 they moved away from the bustling center to a southwestern suburb on a street formerly called Besenscheuerweg. At this location (the original building no longer exists), Einstein worked on his final draft of the special theory of relativity and postulated the mass-energy equivalency.

A year later, in June, the Einstein family returned to Kirchenfeld, taking up quarters at Aegertenstrasse 53. In the following year the Patent Office was moved to the 'old post office' near the train station. Café Bollwerk, where the recently awarded Doctor of Philosophy met his friends and colleagues after work, was just across the busy street. In 1906 the University of Zurich had finally accepted Einstein's second formally submitted thesis, on a new determination of molecular dimensions. So he was able to apply for a *Habilitation* degree at the University of Bern to qualify himself for academic teaching. Still employed full-time at the Patent Office in 1907, Einstein was already working on his first attempt to generalize relativity theory. His thesis on radiation theory was accepted by the University of Bern in 1908 and he offered lectures there for the next two terms in the palacial environs of the university's new main building. By now his revolutionary work had begun to attract the attention of influential physicists abroad. In 1909 the patent examiner accepted an appointment in Zurich as extraordinary professor in the young field of theoretical physics and the Einstein family of three left the quaint Swiss capital, only to return as occasional visitors of their intimate Bernese friends. ■

Errata

In Europhysics News 35/5, page 145, the article "The self-similar rippling of leaf edges and torn plastic sheets" should not have been accredited solely to M. Audoly. The correct listing of authors is:

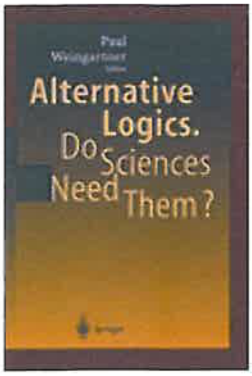
Basile Audoly, Laboratoire de Modelisation en Mecanique, UMR CNRS 7607, Universite Pierre et Marie Curie, 4 place Jussieu, 75252 Paris Cedex 05, France

Arezki Boudaoud, Laboratoire de Physique Statistique, UMR 8550, Ecole Normale Superieure, 24, rue Lhomond, 75231 Paris Cedex 05, France

Benoit Roman, Physique et Mecanique des Milieux Heterogenes, UMR 7636 CNRS/ESPCI, 10 rue Vauquelin, 75231 Paris CEDEX 5, France.

Eran Sharon, The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem, Israel.

BOOK REVIEWS



Alternative Logics. Do Sciences Need Them?

Paul Weingartner (Ed.), Berlin: Springer Verlag, 2004, Cloth, ISBN 3-540-40744-8, Price: € 85.55

Physicist draw conclusions from the assumptions that constitute their hypotheses, models and theories, and they make inferences from experimental results. Succinctly, they *reason*. Logic is the art of reasoning. Hence physics students should first of all study logic and then physics. And *mutatis mutandis* for any other branch at the tree of knowledge. This was Aristotle's view on logic: an indispensable intellectual skill that everyone should master who wants to work in the business of knowledge production. Yet physics students do not follow courses in logic. They learn how to reason *in passing*, so to speak. Aristotle also thought there was a single logic, just as there was a single geometry and a single arithmetic. The plural of logic and geometry did not even exist. Famously Kant elevated logic, geometry and arithmetic to the status of *a priori* knowledge, somehow encoded in our brains, which makes experience possible but is devoid of any empirical content.

In the late 18th century non-Euclidean geometry was discovered. Nonetheless one could (and one did) still maintain that *Euclidean* geometry was the science of the space that surrounds us; all other geometries did not correspond to reality, they were mathematical fantasies of inquiring minds. And then there was, in the beginning of the 20th century, Einstein and his theories of relativity. The rest is history. Although in the 19th century Aristotelian logic was extended, superseded and made rigorous by logicians like George Boole and Gottlob Frege, at the beginning of the 20th century there was still a *single* logic, which we now call *classical logic*. It deals with sentences about whatever subject-matter that can be either true or false, so-called *declarative sentences*. But during the course of the 20th century many different logics were formulated: different rules of reasoning, different 'logical truths', properties of declarative sentences different from true and false (such as necessary, contingent, possible, impossible, indeterminate, neuter), non-declarative sentences (such as questions, warnings, orders, requests, imperatives). Today there is a plurality of logics. Besides classical logic, there is *intuitionistic logic* (which governs a very careful way of doing mathematics, called *intuitionism*), *deontic logic* (which concerns ethics), *modal logic* (which concerns necessity and possibility), *time logic* (which concerns past, present and future, and more complicated temporal ascriptions), *epistemic logic* (about knowing), *doxastic logic* (about believing), *inductive logic* (which concerns probability and confirmation), *paraconsistent logic* (which admits contradictions) and *fuzzy logic* (which admits uncertainty and vagueness).

Physicists use a *deductive logic*, which guarantees that one arrives at true conclusions whenever one starts to reason from true premises, and some *inductive logic*, which deals with the relation of experimental results supporting, confirming or corroborating theories. Which inductive logic they use is a controversial subject, notably among philosophers of science. The deductive logic they use seems to be good old classical logic, just as virtually all mathematicians and other scientists do.

But in 1936 John von Neumann and Gareth Birkhoff argued that the deductive logic of quantum mechanics is *not* classical logic but *quantum logic*, which they devised. Even physicists sometimes need an alternative logic, or so they argued.

Alternative Logics is a panoramic overview of several logics, with an emphasis on the question whether science needs them. There is no single correct answer. It all depends on what you think science needs them *for*. The quality of the various contributions varies. Some are excellent (all more-or-less review essays), in particular those concerning quantum theory (Peter Mittelstaedt, Paul Weingartner, E.W. Stachow) and another, informative introductory essay by Evandro Agazzi, that answers the question 'Why is it logical to admit several logics?' A physics library could take pride in having a copy of *Alternative Logics* on its shelves.

F.A. Muller, Institute for History and Foundations of Science
Faculty of Physics & Astronomy • Utrecht University
f.a.muller@phys.uu.nl ■

Books available for review

6th Conference on Dynamical Systems - Theory and Applications Proceedings
J. Awrejcewicz, J. Grabski, J. Nowakowski, 2002

Accelerator Driven Subcritical Reactors
H. Niefenecker, O. Meplan, S. David, IOP Publishing (Series in Fundamental a. Applied Nuclear Physics), 2003

Advanced Electromagnetism and Vacuum Physics
P. Cornille, World Scientific Series in Contemporary Chemical Physics (Vol 21), 2003

Asymptotic Giant Branch Stars
H. J. Habing, H. Olofsson, Springer, 2004

Atomic And Molecular Spectroscopy. Basic Aspects and Practical Applications (Fourth Edition)
S. Svanberg, Springer (reedition of 1991), 2004

Astronomy. Principles and Practice (Fourth Edition)
A.E. Roy, D. Clarke, IOP Publishing, 2003

Autobiography
J. Awrejcewicz, Department of Automatics and Biomechanics, 2002

Beyond Measure. Modern Physics, Philosophy and the Meaning of Quantum Theory
J. Baggott, Oxford, 2004

Biophysics, An Introduction
R. Cotterill, Jon Wiley & Sons, Inc., 2002

If you are interested in reviewing books, please send us your name, and contact co-ordinates, along with the your field(s) of specialisation to:

Book Reviews, EPS Secretariat
BP 2136, 68060 Mulhouse Cedex, France

LABORATOIRE LEON BRILLOUIN
European Research with Neutron Beams

CALL FOR PROPOSALS

Laboratoire Léon Brillouin

EUROPEAN COMMUNITY - ACCESS TO RESEARCH INFRASTRUCTURES
NMI3 – INTEGRATED INFRASTRUCTURE INITIATIVE FOR NEUTRON SCATTERING AND MUON SPECTROSCOPY – CONTRACT N° RII3-CT-2003-505925

LLB has been recognized by E.U. as a major infrastructure dedicated to research on the structure and dynamics of condensed matter by neutron scattering or imaging. The neutron beams are supplied by Orphée, one of the highest flux and most modern reactors in Europe, equipped with one hot and two cold sources, making available neutrons of any wavelength between 0.7 and 15 Å.

THE 24 NEUTRON SCATTERING AND IMAGING FACILITIES AT LLB - ORPHEE – SACLAY
(including diffractometers for single crystals, powders, liquids and materials science, small-angle scattering instruments, reflectometers, triple-axis, time-of-flight and spin-echo spectrometers for inelastic scattering, and neutron radiography)

are open to Scientists from Member States in the European Union (France excluded) and from the Associated States (*), wishing to perform experiments with neutron beams in condensed matter physics, chemistry, materials science, biology or geosciences.

(*) : BULGARIA, ICELAND, ISRAEL, LIECHTENSTEIN, NORWAY, ROMANIA, SWITZERLAND, TURKEY

Experimental proposals must be submitted in writing using Application Forms (which can be found on our web-site)

DEADLINES FOR PROPOSALS ARE : APRIL 1ST AND OCTOBER 1ST OF EACH YEAR

The written proposals will be examined by a peer review international Selection Panel on the basis of scientific merit and priority to new users and young scientists

- **Access is provided free of charge for the selected user teams**
- **Travel and subsistence up to two users may be reimbursed by the programme**

Application Forms, informations about the NMI3 programme and the LLB facilities can be obtained from :

SCIENTIFIC SECRETARY - NMI3 PROGRAMME
LABORATOIRE LEON BRILLOUIN, CEA / SACLAY
F - 91191 GIF-SUR-YVETTE, FRANCE

Phone : 33 (0) 1 69 08 60 38 Fax : 33 (0) 1 69 08 82 61
e-mail : experience@llb.saclay.cea.fr Web site : http://www-llb.cea.fr

ICCMP FELLOWSHIPS
Brasília
Brazil

The International Center for Condensed Matter Physics of the University of Brasilia has openings for five Visiting Full Professor and fifteen postdoctoral one-year positions beginning in August, 2005 in the areas: Strongly Correlated Systems (theory), Quantum Wires and 2DEG (theory), Ab Initio Calculations for Nanostructures (theory), Field Theory and Critical Phenomena (theory), New Materials and Applications (experimental).

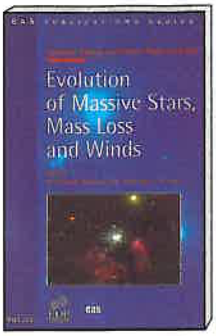
Applications should be made by e-mail before March, 31st. Later applications may also be considered depending on developments.

For more detailed information please visit our website http://iccmp.unb.br or contact Prof. A. Ferraz at visitingpositions@iccmp.org.

EDP SCIENCES

EAS Publications Series

www.edpsciences.org/eas



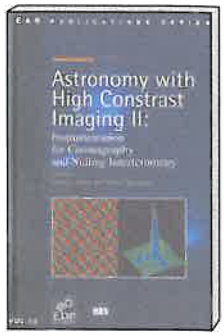
Evolution of Massive Stars, Mass Loss and Winds

M. Heydari-Malayeri, Ph. Stee and J.-P. Zahn, Eds.

In spite of their relatively small number, massive stars play a key role in several aspects. They are the principal sites of nucleosynthesis, and because most of their matter is ejected by their winds and in the final supernova explosion, they are responsible for the chemical evolution of their host galaxy, and thus of the Universe.

A selection of lecture notes are in this volume, and it aims at the largest possible readership, among researchers and students in physics and astrophysics.

Vol. 13 • 2004 • 2-86883-767-0 • 360 p. • 57 EUROS

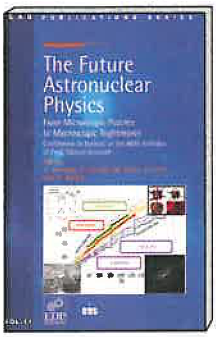


Astronomy with High Contrast Imaging II

C. Aime and R. Soummer, Eds.

The main purpose of this school was to study and compare between them the various techniques (apodisation, coronagraphy, nulling) that can lead to exoplanetographs, i.e. instruments able to directly record the light coming from planets orbiting stars other than the sun. Implementing an exoplanetograph that will actually work is a very ambitious project considering the extreme faintness of these planets compared to their parent stars

Vol. 12 • 2004 • 2-86883-766-2 • 360 p. • 56 EUROS



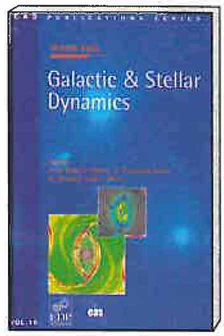
The Future Astronuclear Physics: From Microscopic Puzzles to Macroscopic Nightmares

Conference in honour of the 60th birthday of Prof. Marcel Arnould

A. Jorissen, S. Goriely, M. Rayet, L. Siess and H. Boffin, Eds.

This book identifies a few challenging problems in astronuclear physics, and provides prospects for future developments in abundance determinations in stars and modeling of their atmospheres, in stellar evolution, in multi-D modeling of stellar explosions, and in experimental and theoretical nuclear physics for astrophysics.

Vol. 11 • 2004 • 2-86883-750-6 • 262 p. • 45 EUROS



Galactic & Stellar Dynamics

C.M. Boily, P. Patsis, S. Portegies Zwart, R. Spurzem and C. Theis, Eds.

The workshop Galactic Dynamics was held from September 3 to 6 in Porto, Portugal, as part of the 2002 edition of the Joint European & National Astronomy meeting (JENAM).

The scientific agenda of the workshop consisted of 32 oral and 12 poster presentations. A total of 40 participants joined in the discussions. The oral presentations were split thematically over three days. The topics covered were (broadly): 1) galaxy dynamics and morphology; 2) galaxy formation & environment, dark matter; and 3) stellar clusters. Two invited reviews opened the debates, followed by shorter presentations. This format proved easy on the audience, and well-suited for a workshop of this scope

Volume 10 • 2003 • 2-86883-701-8 • 240 p. • 36 EUROS

ALREADY PUBLISHED

Magnetism and Activity of the Sun and Stars: *An International Conference to Honor the Work of Jean-Louis Leroy*
J. Arnaud et N. Meunier, Eds.
Vol. 9 • 2003 • 2-86883-646-1 • 394 p. • 56 EUROS

Astronomy with High Contrast Imaging: *From Planetary Ssystems to Active Galactic Nuclei*
C. Aime et R. Soummer, Eds.
Vol. 8 • 2003 • 2-86883-687-9 • 376 p. • 56 EUROS

Final Stages of Stellar Evolution
C. Motch, J.-M. Hameury, Eds.
Vol. 7 • 2003 • 2-86883-650-X • 364 p. • 52 EUROS

Observing with the VLT Interferometer
G. Perrin, F. Malbet, Eds.
Vol. 6 • 2003 • 2-86883-652-6 • 296 p. • 47 EUROS

Radiative Transfer and Hydrodynamics in Astrophysics
Ph. Stee, Ed.
Vol. 5 • 2002 • 2-86883-621-6 • 190 p. • 25 EUROS

Infrared and Submillimeter Space Astronomy - *An International Colloquium to Honor the Memory of Guy Serra*
M. Giard, J.P. Bernard, A. Klotz, I. Ristorcelli, Eds.
Vol. 4 • 2002 • 2-86883-612-7 • 426 p. • 65 EUROS

Star Formation and the Physics of Young Stars - *Summer school on Stellar Physics X*
J. Bouvier and J.-P. Zahn, Eds.
Vol. 3 • 2002 • 2-86883-601-1 • 277 p. • 40 EUROS

GAIA: A European Space Project
O. Bienaymé and C. Turon, Eds.
Vol. 2 • 2002 • 2-86883-597-X • 394 p. • 60 EUROS

Active Galactic Nuclei in their Cosmic Environment
B. Rocca-Volmerange and H. Sol, Eds.
Vol. 1 • 2001 • 2-86883-563-5 • 190 p. • 30 EUROS

eas

EDP Sciences
17 av. du Hoggar • B.P. 112 • 91944 Les Ulis Cedex A • France
Tel. 33 (0)1 69 18 75 75 • Fax 33 (0)1 69 86 06 78 • subscribers@edpsciences.org