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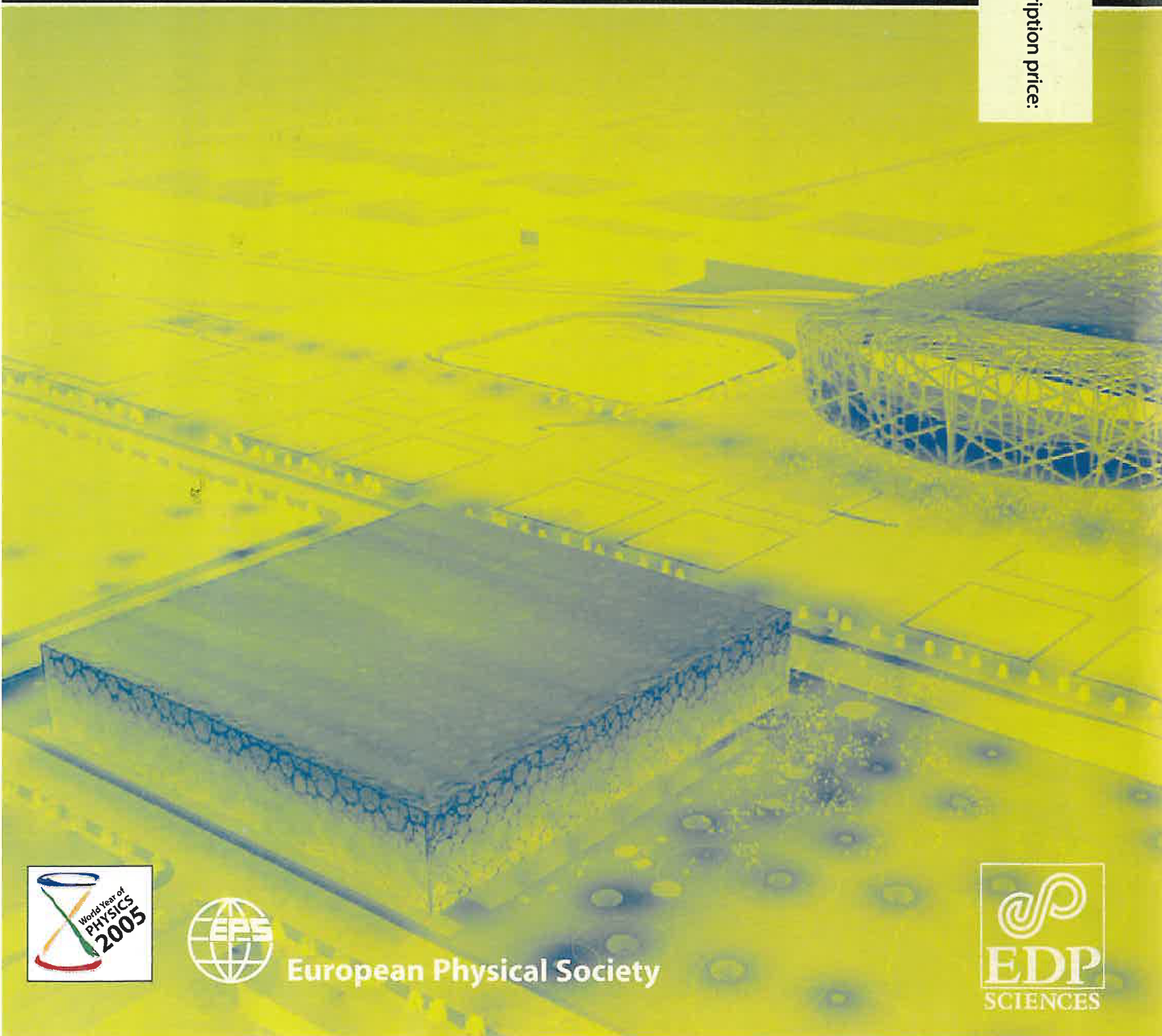

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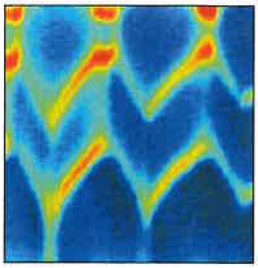

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NEWS, VIEWS AND ACTIVITIES

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Physics education

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Engineering College of Aarhus • DK-8000 Aarhus, Denmark

Having just finished rereading *Einstein lived here* by Abraham Pais it is with a strange notion I write this commentary. Einstein who died 50 years ago, created a decisive foundation for modern physics exactly 100 years ago. He was an immensely popular figure in his days, both among ordinary people as well by the leaders of this world. He still is today.

To commemorate his work 2005 has been named the *World year of Physics*. Again, when writing these lines, hundreds of activities are being carried out through the world. More people than ever will be given a unique possibility to learn about physics, explained by the very best physicists.

People will become acquainted with the beauty and logic of physics a logic that together with advanced technologies has proven so strong in transforming our societies and our lives. Physics is in nearly all aspects a success story that any other business should envy was it not for one thing. The customer base is weak: the young students don't like physics.

As in all other areas of life physics is a human activity. Progress is ensured by talented individuals that advance the field through a combination of skills, insight, dedication and hard work. The reason we admire "our" great physicists are exactly for these reasons as they combine the very best of human activity and at the same time advance their societies.

That was the way we all used to think of physics. We entered the field ourselves, because we simply could not stay away from it. We studied hard and we were lucky enough to find jobs within physics. A career in physics and in science in general, was seen as the ultimate life and so it was. But not any longer is this the case.

A team of physicist, lead by Svein Sjöberg of Oslo University, has conducted a comprehensive study of the relevance of science education (ROSE) among young students in 30 countries around the world. The results of this investigation leave room for reflection in the physics community.

The ROSE project investigates in closer detail the status of science education in a large group of countries. In most countries the students acknowledge the importance of science and technology (S&T) as important for society, that S&T can find cures for diseases and that it will make work more interesting. The same students, however, do not trust scientists nor find S&T neutral and objective. Worst of all, these students dislike S&T at school and they would not consider becoming a scientist themselves. What is true for boys are even truer for girls.

This is a challenge EPS must face with a future of physics different from what we have become used to. There will still be room for new Einstein's and Bohr's, but we must make room for more. We must develop a physics culture better in tune with society and the expectations of the next generation of physicists. Education is the only tool we know of in this respect.

This was the subject of an EPS executive council meeting held in Vilnius in February. This *Journée de Réflexion* on *'Education'* brought together educational specialists from a number of countries and organisations working with educational issues and outreach activities. Réflexions centred on two distinct issues, an analysis of the present situation exemplified by the extensive ROSE investigation and a solution phase, where several speakers presented different models for actions.

Henrik Busch gave a vivid account of the results of ROSE in Denmark, Claus Madsen of EiroForum presented a model for science outreach conducted by the large research organisations in Europe and Erik Johansson of the EPS Education Division described the Stockholm model of science outreach through Alba Nova, the house of science. Jon Ogborn presented the impressive IOP initiative on *Advancing Physics*, Jens Holbeck introduced HOT physics (higher order thinking) and Saul Vingeliene presented impressive figures for the development of science education in Lithuania.

The executive committee decided to maintain focus on educational issues. Thus a follow-up réflexion will be held in Bern July 8 2005 prior to the EPS General Conference and just following the EPEC conference at Bad Honnef July 4-7, 2005. The EPS council will take part in the educational réflexion together with invited practitioners.

To highlight science education is by no means new. Many research groups work with educational themes and much is known about possible solutions to the problems illuminated by ROSE. We are dealing with a community that has developed cures for others, but not yet have learned how to cure ourselves. There is a strong focus on science, technology and innovation and a lesser focus on education, in particular on education in the preuniversity sector. There is much focus on the brilliant science students and less focus on other students with other talents. This poses a democratic problem if actions are not taken now.

EPS is in a unique position to mediate best educational practices among its large membership. Some of us who met in Vilnius continue in Bern and hopefully along the road will develop a keen understanding of the importance of improved educational practices in physics education. All of us, EPS, its divisions and affiliated EU networks on physics education must walk in unison to work to improve the present situation. ■

ROSE project

The Relevance of Science Education Project (ROSE) is an international project, involving over thirty countries, based at the University of Oslo in Norway under the leadership of Professor Svein Sjøberg. The research in England is being conducted by Professor Edgar Jenkins and Nick Nelson at the University of Leeds. The project seeks to establish what students think of their school science classes, what they would like to learn in their school science education, their views about a range of environmental issues, and what research they would wish to undertake if they were practising scientists. The project thus differs from other international comparative studies where the emphasis is on the curriculum as a broad explanatory factor underlying student achievement (TIMSS) or on the extent to which education systems prepare students to become lifelong learners and informed citizens (PISA). It also differs from these studies in including data from a larger number of developing countries. The ROSE project thus reflects the recent growth in interest both in comparative studies and in identifying and responding to the 'student voice' in science education.

The project is funded by the Research Council of Norway and the University of Oslo and, locally, by the University of Leeds.

features

Quantum physics in quantum rings

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The symmetry of a ring system is crucial for classical and quantum effects. Mathematically speaking a ring is a non-singly connected geometry. In quantum mechanics the ring symmetry of the benzene molecule gives rise to its delocalized electronic states [1]. In ring geometries strongly connected to external leads the electron wave packets can take two different paths around the ring which gives rise to interference. This is reminiscent of Young's double-slit experiment for photons. The use of charged particles in a ring geometry rather than neutral photons allows the relative phase of the electronic wave function in the two arms of the ring to be manipulated by a magnetic field perpendicular to the plane of the ring. Aharonov and Bohm proposed such a set-up to test experimentally the significance of the magnetic vector potential in quantum mechanics [2]. They predicted that the phase difference of the alternative paths changes by 2π as the flux through the ring is changed by one flux quantum h/q (q is the charge of the particle). Many experiments over the last three decades have demonstrated magnetic field periodic resistance oscillations in ring structures with a phase coherence length longer than or comparable to the perimeter. In mesoscopic physics the Aharonov-Bohm (AB) effect has become a standard tool to quantitatively investigate the phase coherence of transport in metallic [3] and semiconducting systems.

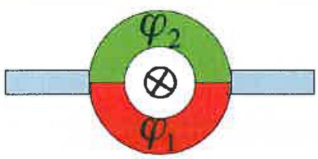
In closed systems with fixed electron number a characteristic magnetic flux-periodic energy spectrum evolves. Such a spectrum can be detected experimentally by measuring electron transport through a lithographically defined quantum ring in the Coulomb blockade regime.

In ring-shaped confined quantum systems the angular momentum becomes a good quantum number. In the case of a single mode ring the single-particle energy levels are given by:

$$E_{m,l} = \frac{\hbar^2}{2m^* r^2}(m-l)^2$$

Here l is the angular momentum quantum number and m is the magnetic quantum number, i.e. the number of flux quanta penetrating the ring at a given external magnetic field. The only material-dependent parameter is the effective mass, m^*. The ring radius is denoted by r. At zero magnetic field, $m = 0$, the ground state has angular momentum $l = 0$, the next two degenerate states are characterized by $l = \pm 1$ and so forth. At finite magnetic field the ground state develops a finite angular momentum which can be translated into a persistent current [4]. In this model the wave functions are plane waves extended around the ring independent of magnetic field.

Aharonov-Bohm effect

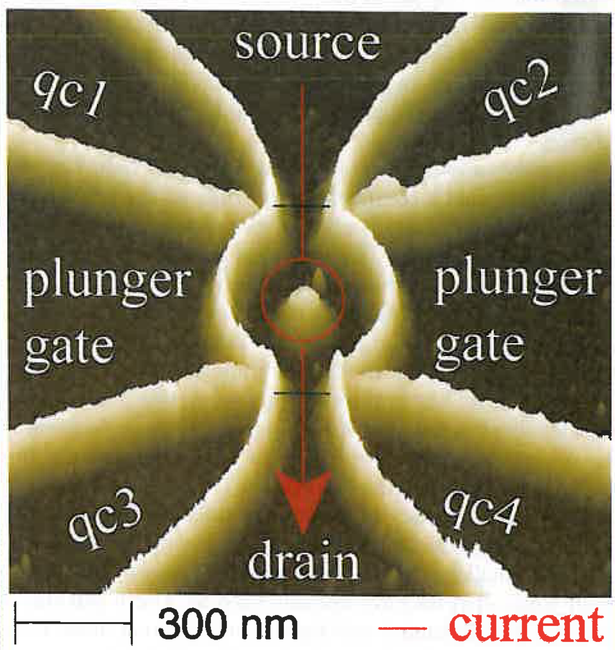


$$\Delta\varphi = \varphi_1 - \varphi_2 = \varphi_{geom.} + \frac{q}{h}\oint \vec{A}d\vec{l}$$

An electron wave coming from the left travels through the ring. The wave propagates in the upper as well as in the lower arm and interferes with itself. The phase accumulation in the upper arm is φ1, in the lower arm φ2. The phase difference Δφ is determined by a constant depending on the details of the wave propagation in the two arms (φ_{geom}) and the magnetic flux penetrating the ring. In the above equation the vector potential in the ring has to be integrated over the ring circumference, q is the particle's charge. As the flux through the ring is changed by one flux quantum q/h, the phase difference changes by 2π. Therefore the interference condition, be it constructive, destructive or in between, becomes periodic in the magnetic flux penetrating the ring. Destructive interference corresponds to a low conductance of the ring, constructive interference to a high conductance. Consequently the conductance of the ring oscillates periodically with magnetic field. All of the above statements are correct if the phase coherence length of the electrons is at least as long as the circumference of the ring.

Fabrication of quantum rings

In this article we describe recent experiments on quantum rings realized in semiconductor heterostructures. Figure 1 shows the



▲ Fig. 1: Micrograph of the quantum ring. The red line marks the current flow from source to drain through the two quantum point contacts and the ring. The lateral gate electrodes termed qc1-qc4 are used to tune the tunnel barriers (indicated by dotted lines) connecting the quantum ring to its leads. The plunger gates allow the electron number on the ring to be controlled (adapted from Ref. 5).

topography of a GaAs-AlGaAs heterostructure containing a two-dimensional electron gas below the surface.
The bright lines are patterned by local oxidation with a voltage-biased tip in a humid environment. The electron gas is depleted below the oxide lines. Voltages applied across oxide lines separating brown regions containing highly mobile electrons do not lead to detectable levels of current flow. Such biased areas can therefore be used as lateral gates to adjust electrical potentials between these regions. The current flowing from source to drain indicated by the red line has to pass between a first constriction, called a quantum point contact (QPC see black dotted lines in Fig. 1), then takes the two possible paths in the ring and leaves again through a QPC constriction. The QPC constrictions can be tuned into the tunneling regime by appropriate voltages applied to the lateral gates termed "qc1-qc4". This way a circular quantum system is realized which is weakly coupled to source and drain reservoirs. The ring contains about 150 electrons and 2-3 radial modes are occupied. For details see Ref. 5.

Electronic transport through quantum rings

Figure 2 shows the conductance through the quantum ring as a function of an energy scale that is deduced from the applied plunger-gate voltage by calibration. The charge on the ring is tuned in steps of the quantum of electronic charge e. Most of the time the conductance vanishes. This is called the Coulomb blockade where the energy provided by the applied voltages is not sufficient to induce another electron onto the ring. At certain voltages or energies, however, the Fermi levels in source and drain are aligned with an energy level in the quantum ring. This level arises from the energy difference of the n and (n+1) many-particle states in the ring. The fluctuating charge on the ring gives rise to the sharp conductance resonances as illustrated in Fig. 2. If temperature is sufficiently low (below 100 mK in this case) and the coupling of the ring to source and drain sufficiently weak so that the broadening of quantum states is less than their spacing then the position and height of each conductance resonance is determined by the properties of a specific quantum state.

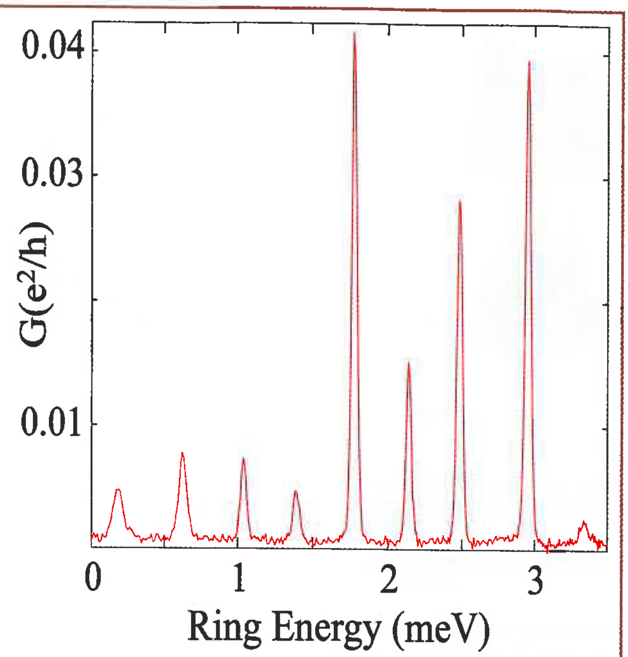
Energy spectrum of quantum rings

In a simple picture the change in voltage position of a conductance resonance can be identified with the change in energy of a single-particle quantum state. Figure 3 shows a conductance map of 5 such experimentally determined states and their behavior as a function of perpendicular magnetic field.

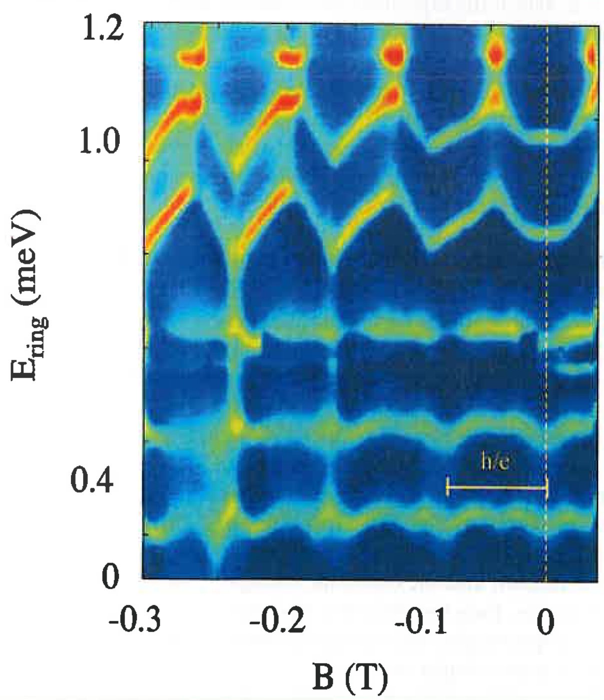
The states are separated by the energy cost to add an electron to the quantum ring. The dominant contribution is the charging energy $e^2/2C$, where C is the capacitance of the system. In addition, the single-particle confinement energy is relevant as well as possible contributions of exchange and correlation. The top two states display a zig-zag movement as predicted by the single-mode ring model presented before. The periodicity is given by one flux quantum h/e per ring area. The fact that the upper two states display similar magnetic field dispersion indicates that their orbital states are related. The behavior can be interpreted as the successive filling of one orbital state with a spin-up and a spin-down electron.

The three lower lying states also show a B-periodic pattern (see Fig. 3), but no zig-zag behavior. They arise from mixing clean angular momentum states by imperfections in the sample. For example, the presence of source and drain contacts perturbs the ring symmetry and mixes angular momentum states.

The ring spectrum therefore contains two typical kinds of states (see Fig. 4): firstly, well-defined angular momentum states

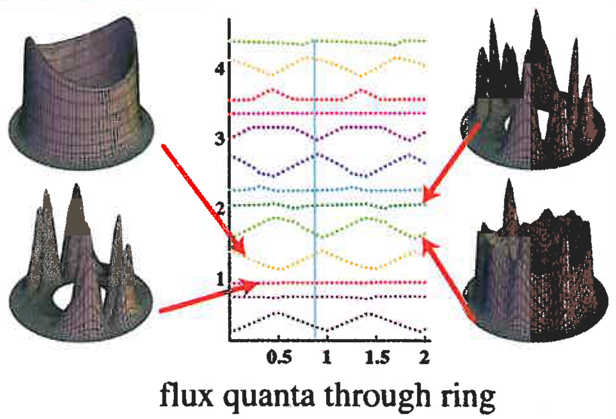


▲ Fig. 2: Conductance in units of the quantum conductance e^2/h through the quantum ring measured by applying a small but finite bias between source and drain contacts. The energy axis is deduced from the applied lateral-gate voltage and an experimentally determined lever arm between voltage and energy.



▲ Fig. 3: Conductance map of ring energy (gate voltage) versus perpendicular magnetic field. Blue means low conductance and yellow/red high conductance. A vertical cut at constant magnetic field displays conductance resonances similar to those shown in Fig. 2. (Adapted from Ref. 5).

features



▲ **Fig. 4:** Calculated magnetic field dependence of energy levels in a quantum ring whose circular symmetry is perturbed. The four wave functions to the left and right are related to the energy levels as indicated by the arrows.

displaying a zig-zag magnetic field dispersion with a plane wave-like wave function extended around the ring; secondly, states containing a mixture of angular momenta with a rather flat magnetic field dispersion and a wave function which is strongly modulated (or localized) at certain locations around the ring. Such a peculiar situation is unique to ring systems, where the non-singly connected geometry plays a decisive role. From the experimental determination of the conductance resonances as a function of magnetic field one can determine the qualitative character of the corresponding wave function. The fact that about 50% of the experimentally detected quantum states display zig-zag behavior as a function of magnetic field indicates the high quality of the ring potential. The slope of such zig-zag states is directly related to their angular momentum and therefore to the persistent current contribution of these states [4]. Our findings here are in qualitative agreement with previous experiments using SQUIDs as detectors for the magnetic moment of such circulating currents.

The spin degree of freedom in quantum rings

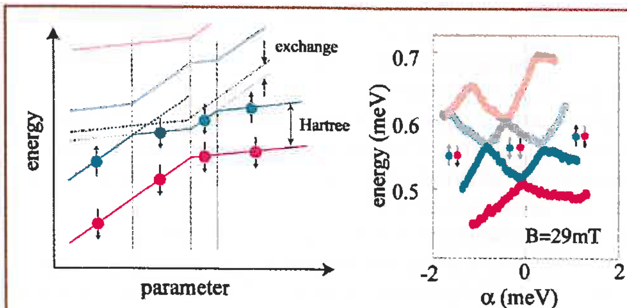
Given the fact that two qualitatively different types of states (with zig-zag and flat magnetic field dispersion) can be detected in quantum rings, the system can be regarded as being similar to a double dot system. A crossing between states of these two types (an unperturbed angular momentum state and a mixed angular momentum state) can be induced by a controlled application of asymmetric gate voltages. Far away from the crossing the two states are filled successively with spin-up and spin-down electrons. Close to the crossing the spin filling sequence is determined by a competition between the single-particle Hartree contribution and the exchange energy. If the exchange energy dominates, then the first two electrons filled in the two levels form a spin-triplet. For increasing Hartree contribution a transition to a spin-singlet occurs [6].

Spin configurations in coupled quantum systems are relevant in view of concepts to use the electron spin in quantum dots as a qubit for quantum information processing [7]. Singlet-triplet transitions can naturally be tuned via the application of a magnetic field, which is usually a slow process. Gate voltages can potentially be tuned very fast. In a configuration as discussed before a singlet-triplet transition can be tuned entirely by electric fields without the assistance of a magnetic field. The fact that the orbital degrees of freedom in quantum rings can be understood on a quantitative basis, can be exploited to analyze and manipulate the spin states in such systems.

Another important physical effect related to the electron spin is the Kondo effect. For quantum dots strongly coupled to their leads, correlations between an unpaired electron spin in the dot and the electrons in the leads give rise to an enhanced Kondo density of states pinned at the Fermi level between two electronic levels. In quantum dots the Kondo effect has been intensively investigated during the last 6 years (see e.g Ref. 8). The Kondo effect can also be observed in quantum rings strongly coupled to their leads [9]. The experimentally observed features related to the Kondo effect, such as a zero-bias anomaly or an enhanced conductance in the Coulomb blockade regime, appear flux-periodic in a magnetic field as in the energy spectrum discussed before. A careful analysis reveals that it is the coupling of the ring states to the leads which strongly oscillates as a function of magnetic field and therefore influences the characteristic Kondo temperature of a particular configuration. In combination with the singlet-triplet transition discussed before the Kondo effect can be investigated for various spin configurations in the ground state of the quantum ring.

Dots and rings

The fabrication of quantum rings relies on the depletion of the electron gas at a small and well-defined spot within the nanostructure. Using an atomic force microscope (AFM) to locally oxidize and therefore deplete an electron gas is a versatile method to pattern tunable ring structures with excellent electronic properties. Figure 6 shows two other examples of ring structures connected to or even containing quantum dots. The left part [Fig. 6 (a)] shows a central ring structure whose circuit is indicated by the green line. On top and bottom two quantum dots flank the ring (red lines). Two additional circuits at the very top and bottom (blue lines) contain quantum point contacts (QPC). All five circuits can be operated separately to detect the coupling of the involved quantum structures. A QPC circuit can be tuned to the tunneling regime, where the QPC conductance is very sensitive to its environment. In this situation, each additional charge on the quantum dot changes the electrostatic



▲ **Fig. 5:** **(left)** Two orbital levels cross as a function of some external parameter, e.g. asymmetric gate voltage. Before and after the crossing the ground state for the lowest two electrons is a singlet state. At the anti-crossing, if exchange dominates the Hartree contribution, the spins of the lowest two electrons are aligned. **(right)** This shows an example of such a situation in our ring. The measured levels have been extracted from peak positions in conductance maps as a function of both ring energy and gate asymmetry α [6]. Between the two blue peak positions the spin state can be tuned with gate voltages.

potential in the neighboring QPC and therefore its conductance. The QPC can thus be used as a non-invasive charge detector [10] in regimes, where direct transport through the quantum dot is experimentally difficult to access. Similarly the central ring structure can be used as a charge detector of the dot [11]. Phase-coherent transport through the open ring gives rise to Aharonov-Bohm oscillations in the conductance. If the charge on the quantum dot is changed by one electron then the electrostatic potential in one arm of the ring is slightly changed. This changes the overall phase of the wave function and gives rise to a change of the total transmission through the ring, which can be detected experimentally. Such electrostatic coupling between quantum structures is important to understand their cross-talk. For future quantum circuits it will be important to couple quantum systems not just by electrostatic, but by real quantum mechanical coupling involving overlap of wave functions.

The right part in Fig. 6 (b) shows a four-terminal ring structure. Electrons injected through one of the contacts travel ballistically through the ring structure with only a small fraction leaving through the first side arm. In the ballistic phase-coherent regime Aharonov-Bohm oscillations can be observed in a usual two-terminal set-up as well as in three- and four-terminal configurations. The four gate electrodes between the ring contacts can be used to electrostatically squeeze each quadrant of the ring separately. In particular, a quantum dot can be electrostatically induced in each of the four quadrants. We have extensively studied the situation when two quantum dots (indicated by the red circles) appear in two arms of the rings, such that an electron wave packet traveling along the path indicated by the green line passes both dots if an interference signal is detected. The phase evolution of the electronic wave function has been studied experimentally [12] where one dot has been included in one arm of the Aharonov-Bohm interferometer. In the present case the two dots play an important role for the interference experiment. The phase change can be detected when an electron is added to each of the dots separately, to both dots at the same time, or when one electron is effectively transferred from one dot to the other. In many regimes we find that the phase of the electronic wave function is changed by about π as the system goes through a conductance resonance. It is important to note, however, that every component of the system plays a role since phase coherence is maintained. Changing the electron number in one of the dots by one has an impact on the boundary condition of the wave function at several locations in the ring. The interference pattern may therefore develop complicated features which depend on the details of the system and the changes of its components. ■

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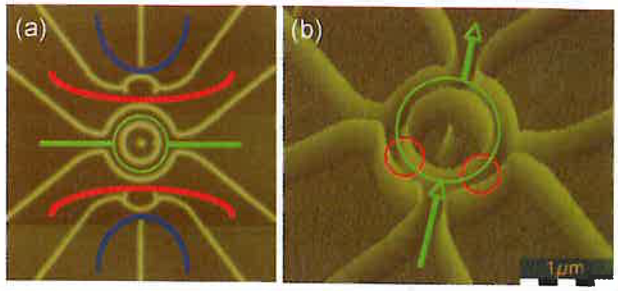

▲ Fig. 6: (a) AFM image of a circuit containing a central ring (current flow indicated by green line), two quantum dots (red line) and two quantum point contacts at the very top and bottom (blue line). The bright lines represent oxide lines below which the electron gas is depleted. Conductances can be measured along each of the colored lines plotted in the figure (adapted from Ref. 11).
(b) Four-terminal ring structure defined by oxide lines (bright lines) as before. By applying lateral gate voltages to the four outer segments the current paths in the ring can be electrostatically squeezed to form quantum dots. Two such possible locations of electrostatically induced quantum dots are indicated by the red circles. For current flow from bottom to top (indicated by the green line) each partial wave has to pass a quantum dot and change its phase correspondingly (adapted from Ref. 13)

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Geomagnetism in Finland: the lasting legacy of Johan Jakob Nervander

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In the early 19th century electromagnetism was born as magnetism and electricity were found to be closely related to each other. Hans Christian Oersted demonstrated that an electric current causes forces that deflect a magnetic needle. André Marie Ampere discovered the electric current generated in a closed circuit by a changing magnetic field. This effect of magnetic induction offered a new paradigm for geomagnetism, a new solution to an old riddle: *what is the cause of the Earth's magnetism?* Is it a huge electromagnet sustained by internal process of magnetic induction?

Inspired by such questions British, French, German and Russian scientists set up about 20 magnetic observatories throughout the world. In Europe the so-called Magnetic Union was founded by Gauss and Weber in Göttingen to organise coordinated magnetic observatory campaigns. To reveal the significance of magnetic variations, simultaneous magnetic recordings made with similar observatory equipment were needed.

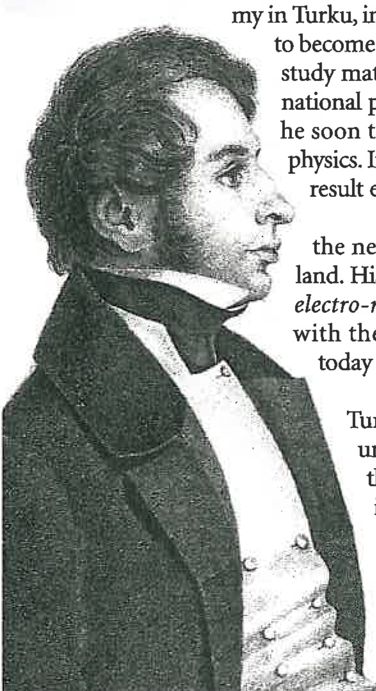
Today there are about a hundred observatories. The basic principles of magnetic observatory measurements remain as they were 160 years ago.

Finland's father of geomagnetism

Johan Jakob Nervander (1805-1848) studied at the Royal Academy in Turku, initially in the humanities. He aspired to become a poet, but the competition with his study mate Johan Ludvig Runeberg, later the national poet of Finland, was formidable and he soon turned to the sciences, particularly physics. In 1827 he matriculated with the best result ever recorded in Turku (Fig. 1).

Nervander was the first promoter of the new electromagnetic science in Finland. His doctoral dissertation *In doctrinam electro-magnetismi momenta* (1829) dealt with the construction of a device which today we call a galvanometer.

After witnessing the Great Fire in Turku he took part in the move of the university to Helsinki in 1828. It was there that he made his main scientific contributions. With the support of a travelling studentship, he made an extensive tour of Europe between 1832 and 1836, visiting the leading laboratories in Sweden, Denmark, Germany, France and Italy. Geomagnetism became his main interest. In Paris he lectured on the construction of a new galvanometer, his *tangentbussol*. Careful calibration of the new instrument showed that the tangent of the deflection angle of the magnetic needle was proportional to the current to be measured. Nervander's *tangentbussol* is still on display in the Arppeanum, the Helsinki University Museum (Fig. 2).

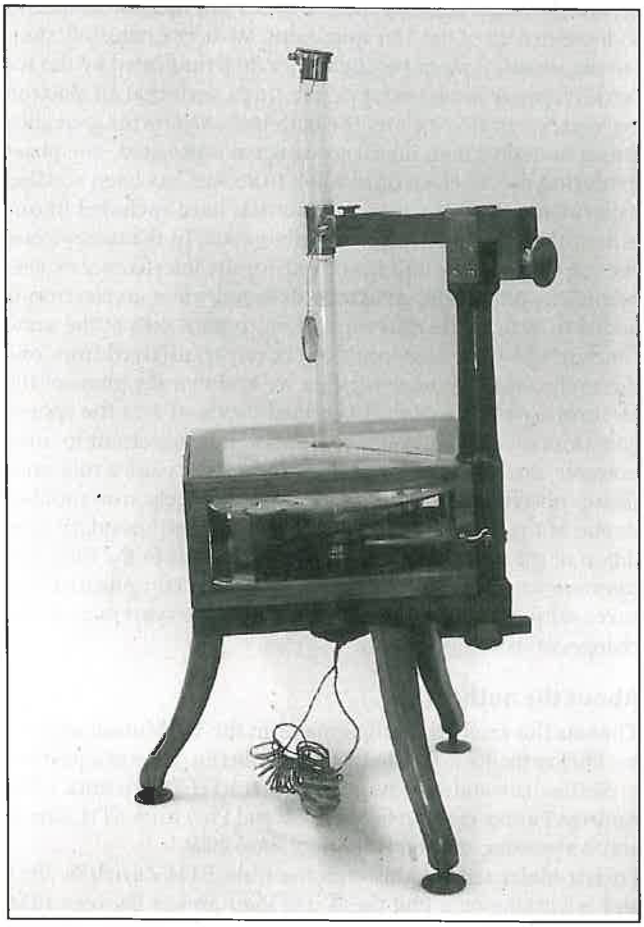


▲ **Fig. 1:** Johan Jakob Nervander (1805-1848).

The foundation of the magnetic observatory

Nervander returned home via St. Petersburg, as the ice conditions made the voyage from Stockholm to Helsinki unpredictable. In St. Petersburg he met Academician Adolf Kupffer, who was to support his ambitions for an observatory in Helsinki.

Since the 1820s several magnetic observatories had been set up in Russia ranging across an area from St. Petersburg on the Baltic Sea to Sitka, Alaska, in the northern Pacific Ocean. Discussions in St. Petersburg pointed to Helsinki as a possible place for an observatory, extending the Russian network. The correspondence between Adolf Kupffer, the director of the Russian Science Academy in St.. Petersburg, and Gustaf Gabriel Hällström, Professor of Physics at the university in Helsinki, and then later with Nervander, shows how this project took shape.



▲ **Fig. 2:** Nervander's *tangentbussol* (galvanometer). Nervander gave a report on this construction in 1833 while in Paris. The apparatus was damaged during the bombings of Helsinki in the war 1944 and the glass parts are replaced. Helsinki University Museum.

In 1838 the university in Helsinki received a letter from its Chancellor expressing that His Imperial Highness approved the founding of a Magnetic Observatory in Helsinki in association with the university.

It was decided to build the Magnetic Observatory in a corner of the Central Park (Kaisaniemi Park) in Helsinki. The assigned architect, Engel, drew up the first plans for a large building for staff and the director's family, together with a smaller one for the calibration of the magnetic instruments (Figs. 3 and 4). Nervander was to be allowed to keep cattle for his own use on the condition their smell would be of no nuisance to the people walking in the park.

As the first Director of the Magnetic Observatory he also had the title of Extraordinary Professor at the university. The personnel under his direction numbered twelve, more than in any other institute at the university.

When the magnetic measurements started in July of 1844, the readings of the instruments were taken every ten minutes. This ambitious programme was followed during the years 1844-1856. After that the readings were taken once per hour and, finally, between 1897 and 1911, only three times per day. In parallel with the magnetic measurements, full-scale meteorological and climatological observations were made hourly. Eventually the electric tram traffic in the neighbourhood of the Observatory disturbed the measurements and the readings ceased in 1912.

Magnetic equipment

The instruments for continuous monitoring of geomagnetic variations at the Helsinki observatory were manufactured in Göttingen, Germany.. The principles of the observatory magnetometers were invented by Carl Friedrich Gauss in 1836-1837 and described in the proceedings of the Göttingen Magnetic Union (Gauss, 1838). Gauss was the leading scientist in the field of geomagnetism and inventor of many geomagnetic instruments with his colleague Wilhelm Weber. The observatory routines in Helsinki were also based on those of the Göttingen observatory.

There were three magnetic vector components to be observed: the horizontal field (H), the declination (D), and the vertical component (Z). D is the angle between the H-vector and the true magnetic north direction.

As an example, fig. 5 shows the magnet for D- and H-observations. Similar types of magnets as that in Göttingen were in use in all magnetic observatories through the 19th century. The weight of the magnet was 1,8 kg and the dimensions were 63 cm x 3,7 cm x 1 cm. For D-measurements, the magnet was in the same direction as the H-vector pointing thus towards the magnetic north. For H-observations the position of the magnet was perpendicular to the H-vector in the east-west direction. The changes in the direction of the magnet were observed by a telescope on a scale reflected by a mirror fixed to the magnet, fig. 5. The distance between the magnet and the telescope was about 7 meters.

Historical background

After the war between Sweden-Finland and Russia, 1808-1809, Finland was annexed to Russia as an autonomous Grand Duchy. Russia had a positive policy towards Finland and the university benefited from it. The capital was also moved from Turku to Helsinki in 1812. After the Great Fire in Turku in 1827 the university was moved to Helsinki, and re-established in the new city centre under the name of the Imperial Alexander University in Finland.

Essentially the same observational procedure and equipment were in use in all magnetic observatories for about 150 years. Photographic recording systems came in during the late 19th century. Since about 1970s all geomagnetic observatories have been equipped with magnetic recording instruments without magnets, for example using protonmagnetometers or flux-gate instruments.

Johan Jakob Nervander (1805-1848

1805 • Johan Jacob Nervander was born on 23 February 1805 in Uusikaupunki (Nystad). His father was a pharmacist and merchant (owning partnerships in merchant ventures). However, these speculations turned to economical ruin, and he had to sell the pharmacy rights, whereafter the family moved to Oulu (Uleåborg).

1820 • Having passed the primary school in Oulu and the cathedral school in Turku Nervander, at the age of 15, passed his matriculation exams and entered the academy in Turku.

1827 • Nervander finished his *pro gradu* thesis and obtained his M.Sc. The matriculation score, 30 out of 33, was the best result ever recorded at the Academy.

1829 • Nervander wrote a dissertation for a docentship and was appointed the same year. He was also acting professor of physics during the period when Hällström was rector of the university in Helsinki.

1832-1836 • Nervander travelled to several research centres and universities in Europe. He constructed the *tangentbussol* and lectured on this device, thereby earning an international reputation as a physicist.

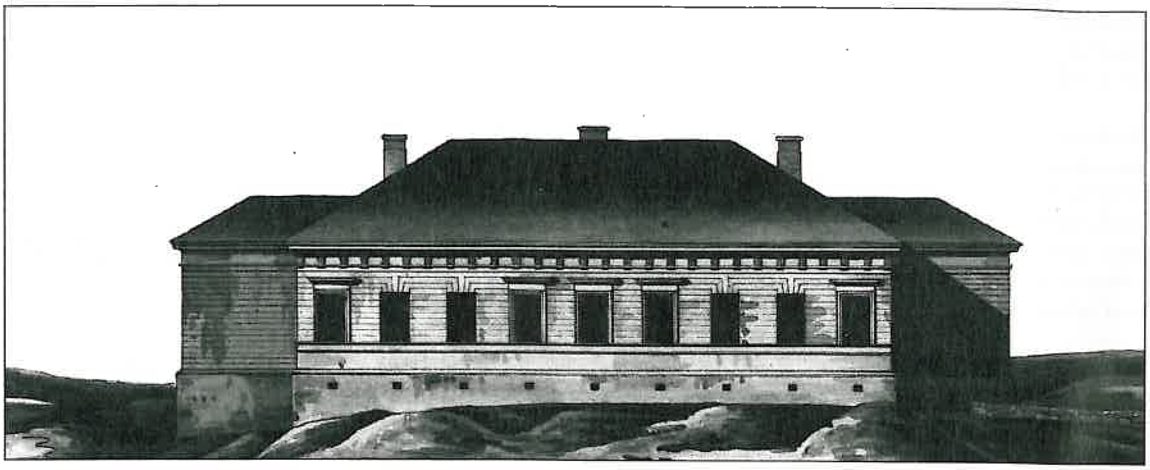
1838 • A magnetic observatory was founded in Helsinki and Nervander was appointed its first director. Nervander also took part in establishing the Finnish Society of Sciences and Letters and was elected president for the year 1847.

1844 • Continuous measurements of variations in the magnetic field of the Earth and normal meteorological observations were begun in the Helsinki Observatory.

1845 • Nervander was appointed professor of physics after the death of Hällström.

1848 • Nervander falls ill with smallpox and dies on March 15.

1991-1996 • The measurement of the magnetic field, started by Nervander, continued for almost 70 years until 1911, when the electric tram traffic in the neighbourhood disturbed these measurements too much. Today this large amount of material which was collected has been analysed and finally published by the FMI's team (Nevanlinna, 2004). The work that Nervander had begun some 160 years previously has thus been completed. The Helsinki magnetic data series is scientifically very valuable, because not much high-quality magnetic data are preserved from other observatories around the world from the middle of the 19th century. The Helsinki data give useful information about geomagnetic variations connected with the long-term changes of the activity of the Sun.



◀ Fig. 3: The main building of the Helsinki Observatory in 1838

The Helsinki magnet, manufactured in Göttingen in 1841 is still suspended from the roof of the lobby of the Finnish Meteorological Institute, demonstrating the changing magnetic field as it did for so long.

The end of the Nervanda era

Nervander also studied climatology, especially the question of how sunspots affect the temperature in the atmosphere. This work won a prize from the Russian Science Academy in St. Petersburg. In the midst of his success Nervander fell ill with smallpox and suddenly died on 15 March 1848. After that Henrik Gustaf Borenius, Nervander's son - in - law, became the Director and the activities at the Magnetic Observatory continued, but without publication.

The importance of magnetic measurements

The magnetic declination and the intensity of the horizontal component of the Earth's magnetic field and, in the beginning, also the vertical component, were noted. The readings from the first period when Nervander was Director were published posthumously in 1850 with an introduction by Borenius. After that, only readings without analysis were made and the number of laboratory journals steadily increased. These journals have only now, in recent times, been found; they are now available in the Archive of the Finnish Meteorological institute (FMI) in Helsinki.

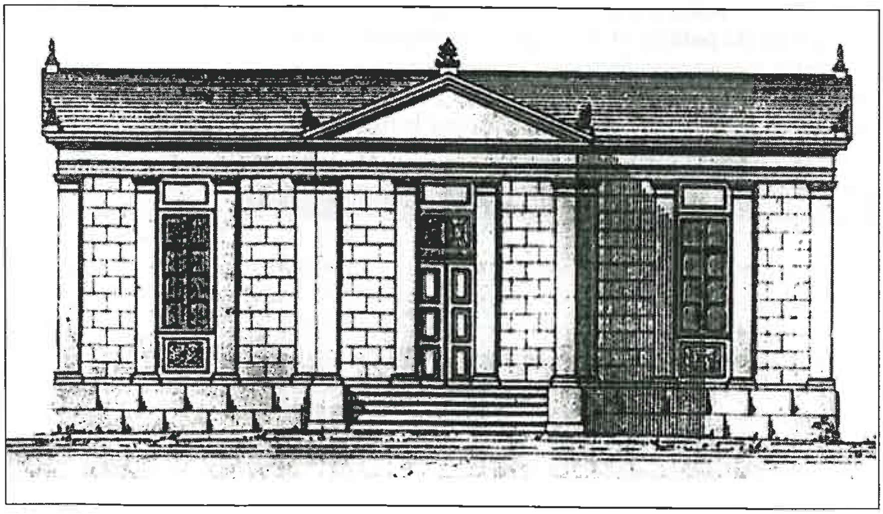
In the 1990s, Dr. Heikki Nevanlinna and his team in the FMI converted the handwritten numbers into electronic form. They carefully analyzed this old material, consisting of about 2,000,000 single readings, and published the results for the full period 1844-1911. Thus the work begun more than 160 years ago by Nervander, and continued under supervision by many Directors thereafter, has finally been completed (Fig. 6).

Long, continuous and homogeneous data series are extremely important when studying slow changes in the geomagnetic field, the so-called secular variation, giving clues to the physical mechanisms sustaining the geomagnetic field inside the Earth. The Helsinki series covers about 70 years.

Transient geomagnetic variations lasting from minutes to days are connected with so-called space weather which characterizes electromagnetic conditions in the near-space around the Earth, in the iono- and magnetospheres. The space weather is ultimately governed by the activity of the Sun, manifested by varying solar corpuscular and electromagnetic radiations. By this means, magnetic observatory recordings give indirect information about the processes regulating the solar energy output. Long-term observations of the space weather indicators tell about slow changes in the solar radiation in the course of 11-year sunspot cycles. For such studies, the Helsinki series provides an outstanding data source covering about six solar cycles. The daily magnetic field values are usually converted into indices (numbers) in a standardized scale, making comparisons of magnetic variations between different observatories possible. The longest of such a series is known as the *aa*-series, starting in 1868 and continuing into the present. It is based on combined observatory recordings in England and Australia. The index series, derived from the Helsinki magnetic observations, yields information about solar activity for 24 years before the start of the *aa*-index series. Thus, the combined *aa*-Helsinki magnetic activity index series covers about 160 years since 1844. During the last 10 years about 40 scientific articles have appeared utilizing the newly available magnetic observations from Helsinki.

The Magnetic Observatory after Nervander

When Borenius, Nervander's son-in-law and successor as Director, withdrew from this position in 1880, the Finnish Society



▶ Fig. 4: A building (Absolute House) for calibration of geomagnetic observatory instruments. It was in operation 1845-1920.

◄ Fig. 5: The great magnet for monitoring changes in horizontal field and declination at the Helsinki observatory (1844-1912). The length of the magnet is about 60 cm and the weight almost 2 kg. Changes in the direction of the magnet were observed through a telescope, at 7 meters distance, that was pointing to the mirror shown above the magnet fixed in the suspension wire.

of Sciences and Letters took over the responsibility for the Observatory. Nils Karl Nordenskiöld, Ernst Biese and Gustaf Melander followed as Directors. During Melander's leadership (1908-1918) the Observatory was reorganised and separated from the Finnish Society of Sciences and Letters, becoming the Meteorological institute, an independent state institute.

So the interest in geomagnetism has long and inspiring traditions in Finland. When the International Geophysical Polar Year (1882-1883) was planned, Karl Selim Lemström (1838-1904), Professor of Physics, was an eager spokesman in support for Finland's participation, due to his advocacy, a temporary magnetic-meteorological observatory was founded in Sodankylä, northern Finland, with six assistants. With this polar station, Finland now took a position among other nations in the scientific community.

The FMI, as the successor of the Helsinki Magnetic Observatory, maintains a permanent magnetic observatory in Nurmijärvi near Helsinki. Another observatory is in Sodankylä, Lapland, under the University of Oulu. In addition, the FMI runs a network of automatic magnetometers monitoring the magnetic component of space weather variations. The network consists of 6 magnetometers in Finland and 21 in other parts of Fennoscandia from Estonia to Svalbard in the Barents Sea. Geomagnetic research is devoted to magnetospheric phenomena and space weather effects on the ground. The spirit of Nervander lives on. ■

About the authors

Peter Holmberg (b. 1938), Emeritus Professor, teaches medical physics in the Faculty of Medicine, University of Helsinki. His research interests are in the field of radiation physics and radiology. He has also written textbooks on physics and biophysics. For many years he has been interested in the history of physics and he has written *The History of Physics in Finland* 1828-1918 and several articles on this topic.

Heikki Nevanlinna (b. 1947), PhD, works as Research Manager at the Space Research unit in the Finnish Meteorological Institute. His scientific expertise focuses on the Earth's magnetic field variations and space weather phenomena including Northern Lights. He has written about100 scientific papers and in recent years also many popular articles on geophysical topics.

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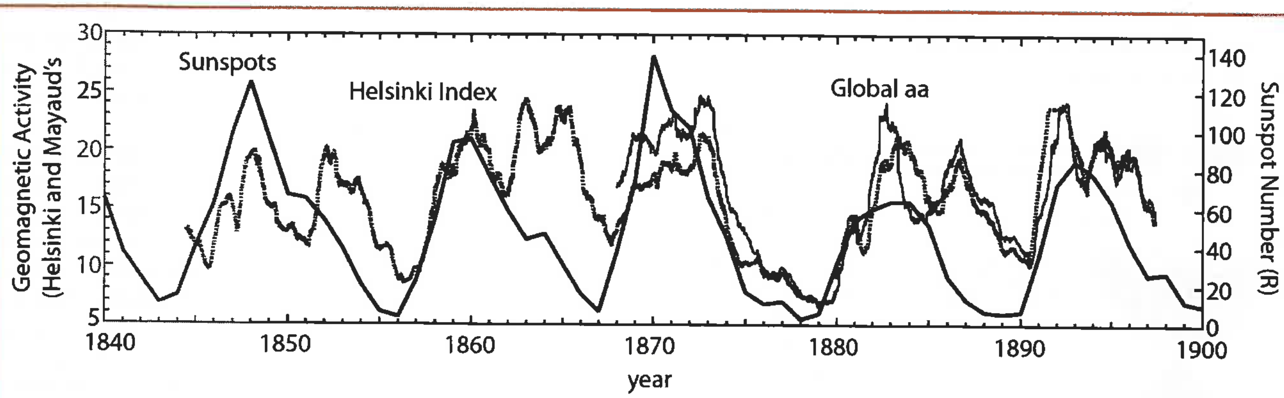

▲ Fig. 6: Dotted line: Magnetic activity index derived from the Helsinki observations 1844-1897.
Thin solid: The longest available global index (*aa*) starting in 1868. • Thick solid: Sunspots in the 11-year solar cycle

Exotic helium dimers: a giant comes out of the cold

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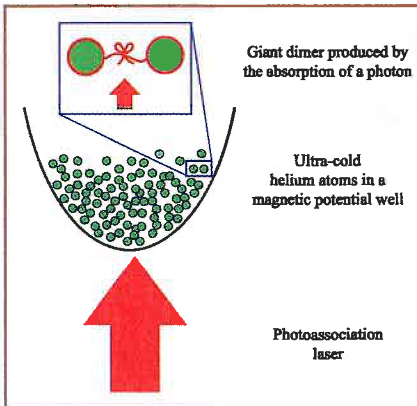
Giant helium dimers can now be produced routinely in the "Cold Atom" group of the Laboratoire Kastler Brossel at the École Normale Supérieure in Paris [1]. The separation between the bound pair of atoms is on the order of 50 nanometres, or nearly one-thousand times larger than normal bond lengths. This size—which approaches that of a virus!—makes these the most distended two-atom molecules ever observed.

The Paris results run counter to the intuitive expectation, based on the well-known fact that helium is chemically inert, that He_2 should not exist. Under normal conditions, this expectation is justified, since the feeble interactions that can bind helium atoms together are completely overwhelmed by thermal agitation at room temperature. However, experiments in 1993 [2] demonstrated the existence of ground-state helium dimers with binding energies of 10^{-7} eV, which corresponds to the mean thermal energy at a temperature of a few milliKelvins (mK). Indeed, sub-mK "ultra-cold" temperatures are also necessary in the Paris experiment and are readily achieved by evaporative cooling in a magnetic trap.

But there are remarkable differences between the Paris dimers and the He_2 molecules observed previously. First, there is the size difference. The mean atomic separation in ground-state He_2 is a few angstroms, which is closer to the size of an everyday dimer such as N_2 and O_2 than to that of the hundredfold-larger giant helium dimer. In addition, the depth of the molecular potential that binds the atoms together is four orders of magnitude shallower for the giant dimer. These huge differences in distance and energy scales result from very different interactions producing the molecular potentials in the two cases. And this points to one of the most dramatic differences of all: whereas the ground-state He_2 molecule is produced in normal three-body collisions, the giant dimer is formed when two metastable (He*) atoms, each carrying nearly 20 eV of electronic excitation energy, collectively absorb a laser photon—a process called photoassociation [3] (fig. 1).



◄ **Fig. 1:** Tens of millions of metastable helium atoms are held in a magnetic trap at a temperature of a few microKelvins, and a laser pulse "photoassociates" atomic pairs to form hundreds of thousands of dimers.

The dipole transition that permits the giant dimer to be formed also allows it to decay, so the structure is strictly ephemeral. But it has enough stability to exhibit extremely well-resolved vibrational spectra, in which the absorption of laser photons occurs only at well-defined and widely separated frequencies. One of the discoveries of the ENS team has been a sensitive method for detecting the absorption signals in their photoassociation experiment, namely through the "calorimetric" effect that decaying molecules have when they cause heating in the surrounding atoms.

The Paris experiment requires helium atoms in the 2^3S_1 (He*) metastable state to be trapped and cooled to microKelvin temperatures. Fortunately, the team can rely on the equipment and techniques that led them to their observation of Bose-Einstein condensation in helium in early 2001 (just weeks after a similar observation by Alain Aspect's group in Orsay) [4]. That observation revealed the macroscopic wave properties that identical atoms collectively display under conditions of extremely low temperature and high density. Such conditions, now reached daily in the laboratory, are more than adequate for the production of giant helium dimers.

Figure 2 shows a diagram of the main components of the experimental setup. The preparation of the atomic sample begins with a beam of helium atoms that is excited into the 2^3S_1 (He*) metastable state by an electrical discharge and emerges into an empty vacuum chamber. A laser beam (wavelength 1083 nm) is directed opposite to the atomic beam, so that whenever an atom absorbs a photon, it receives a decelerating impulse. Repeated absorptions are used to decelerate the atoms from speeds near 1000 m/s to less than 20 m/s over a distance of 2 m. (Note that spontaneous emission, which is oriented randomly, yields no average change in atomic momentum during the deceleration process.) After being decelerated, the atoms are collected at the intersection of several laser beams that form a magneto-optical trap (MOT). In just a few seconds, the MOT can collect tens of millions of He* atoms in a volume of a few cubic mm and cool them to a temperature of about 1 mK.

A final stages of cooling and spatial compression are begun when the MOT's laser beams are extinguished and a specially tailored magnetic field is applied. The field interacts with the atomic magnetic dipole moments to form a potential energy well, or a magnetic trap such as that shown schematically in figure 1. Given a 1-mK starting temperature for the atoms, the walls of the trap are sufficiently high that almost no atoms can escape. Moreover, the walls can be steepened in order to help compress the atomic cloud toward the trap center. This has the effect of increasing the atomic density and therefore the collision rate, which in turn increases the rate of thermal equilibration in the cloud.

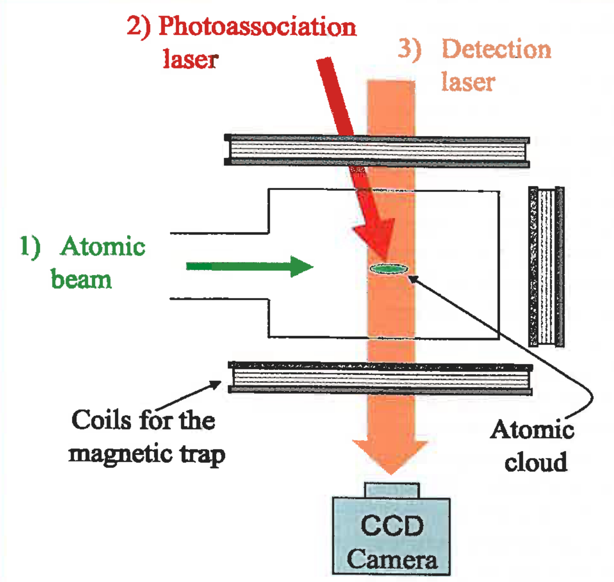
Rapid equilibration is necessary for the "forced evaporation" that is introduced next. This last cooling process employs a radiofrequency (RF) magnetic field to flip the dipole moments of atoms at the outer edges of the trap, so that these atoms are expelled from the cloud. The trap's field gradient ensures that the RF field can be applied in a spatially targeted fashion (analogous to the spatial resolution achieved in magnetic-resonance imaging) and that it will "boil off" only those atoms that are energetic enough to be found at the outer reaches of the trapping potential. This method of cooling, or of selectively removing the particles at the high end of the velocity distribution, is analogous to the forced evaporation that occurs when one blows air over a hot bowl of soup. But in the helium experiment, the cooling (with thermal equilibration) reduces the probability that trapped atoms will get enough energy to reach the magnetic-resonance point and be ejected. For this reason the evaporating RF field is gradually adjusted, or ramped, in order to access atoms lower in the potential well. An RF ramp lasting about ten seconds is necessary to cool the atomic cloud to just a few microKelvins; meanwhile the density climbs to roughly 10^{13} atoms/cm^3.

A key diagnostic for temperature and density in experiments such as this goes by the name "absorption imaging." A near-resonant, large-diameter laser beam is briefly sent through the cloud and is caught on a camera ccd ("charge-coupled-device") sensor. The atoms in the cloud absorb some of the light, and the shadow they leave in the beam is easily captured by the camera and recorded on a computer. Analysis of an image yields the size and optical thickness of the cloud, and thereby the number and density of atoms. The cloud's temperature is obtained when the trap is turned off and the cloud is allowed to expand for a few milliseconds (the increased cloud size indicates the mean atomic speed).

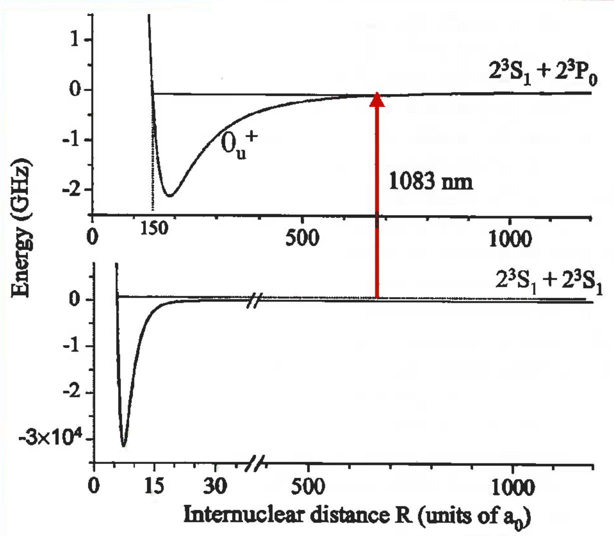
It is remarkable that these techniques can be used to produce samples of metastable helium cold enough to reach Bose-Einstein condensation. For each of the trapped atoms, the 20-eV of energy in the excited electron exceeds the mean thermal energy by ten orders of magnitude. When two such atoms collide, their interaction can destabilize the electronic states and cause a destructive "explosion." This process, known as Penning ionization, tears an electron off of one atom and sends the other atom into its ground state ($^1S_0$). None of the collision products remain trapped, and they all emerge with considerable kinetic energy. This process is the main loss mechanism in traps for helium atoms in the metastable 2^3S_1 state. However, in a spin-polarized, ultracold sample, it is strongly suppressed by the conservation requirement for the total spin projection of the system. During the evaporation/collisional-thermalization procedure, this conservation principle serves as a necessary safeguard against the otherwise certain self-destruction of the atomic sample.

The production of giant helium dimers relies on a very different inelastic collision process, one that is far gentler than Penning ionization. In the process of photoassociation, two He* atoms absorb a laser photon, and the system is excited into a bound state of a long-range molecular potential well. This potential, labeled as "0_u^+" (see fig. 3), is one among a jungle of different possible potentials that arise from the various combinations of atomic quantum numbers. A key feature of all the molecular potentials accessible via photon absorption is a "resonant dipole-dipole" interaction that varies as $1/r^3$ (where r is the internuclear distance) has a range extending to tens of nanometers. This interaction can be attractive or repulsive, depending on the relative orientations of the atomic electric dipoles. However, for a system characterized by the 0_u^+ potential, the atomic fine-structure interaction between the spin and orbital angular momenta of the electrons provides an intriguing modification. It effectively causes internal torques on the atomic dipoles, so that they are oriented so as to produce repulsion at distances shorter than about 10 nm and attraction for distances greater than this. In more technical terms, it causes an "anti-crossing" between attractive and repulsive $1/r^3$ potentials, leaving a local minimum at $r \sim 10$ nm. Thus, two He* atoms that are initially approaching (or receding from) each other in this distance range can absorb a photon from the photoassociation laser and find themselves caught in a potential well. The two once-independent atoms are stuck together in the form of a giant dimer.

In practice, the photoassociation laser is applied for only a few milliseconds, and within each of these pulses, the laser frequency is set to a value within the ~ 2GHz range covering the energy depth



▲ Fig. 2: Diagram of the magnetic trap (its 3 coils around a vacuum chamber) holding atoms that have been decerated, cooled and trapped by laser beams. (1) An atomic beam enters from the left after being decelerated to 20 m/s, and the atoms are captured in a magneto-optical trap (decelerating and trapping laser beams are not shown). The cloud of atoms is subsequently held by magnetic fields and cooled evaporatively to a few microKelvins. (2) A frequency-tunable photoassociation laser with is applied for a few millseconds (3) A probe laser is used to obtain an absorption image of the cloud.



▲ Fig. 3: Interaction potentials for two helium atoms as a function of their separation. Below: The potential for both atoms in the metastable 2^3S_1 (He*) state. Above: The purely long-range (0_u^+) potential well supporting a bound state that is excited through the absorption of a photon from the photoassociation laser. Note the different energy and distance scales for the two curves. The potential below is flat except at extremely short distances. The one above, in which giant dimers are created, is weakly attractive at very long distances.

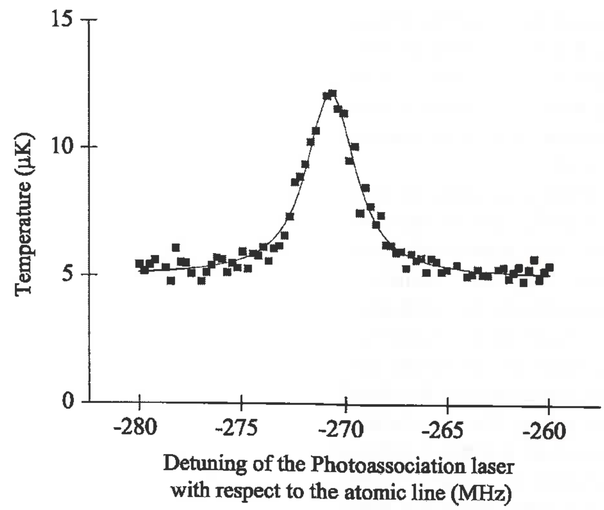
of the 0_u^+ potential well. Subsequent to each application of the photoassociation laser, an absorption image of the trapped cloud is obtained. The images reveal resonant absorption for particular photoassociation frequencies corresponding to the quantized energies of vibrational states in the potential well. This conclusion is supported by two pieces of information: first, there are resonant decreases in the integrated optical density of the cloud, which indicates a loss of independent He* atoms; and second, there is an even more pronounced increase in the temperature of the cloud, which is attributable to the release of kinetic energy that occurs when the giant dimers decay. Figure 4 shows such a "calorimetric" signal for one of the molecular resonances.

In all, five bound states have been found in the 0_u^+ well, and their energies agree (to better than 1%) with those predicted by models involving the internal atomic structure and the resonant dipole-dipole interaction. The agreement is especially remarkable because the computational model completely neglects the uncertain electrostatic repulsion that provides the inner-wall for normal molecules. The fact that the r-dependence of the 0_u^+ potential emerges entirely from the long-range ($1/r^3$) interaction, even for short distances, puts the giant helium dimers in the category of "purely long-range molecules" that were first predicted by Stwalley, et al [5]. However, helium is the simplest atom for which such molecular states have been studied, and the comparison between experiment and theory is consequently simpler and more accurate. In fact, the precision is so high that retardation effects must be included in the model of the molecular interaction.

The convergence of theory and experiment offers an opportunity to characterize the sizes of the giant dimers in more detail. The steep inner wall of the potential yields an inner turning point around 8 nm for all of the bound states. The outer turning points range from about 14 nm for the lowest state in the potential to about 60 nm for the highest state. These are the largest interatomic distances ever observed in any dimer.

A skeptic might object that these so-called dimers are not rightful molecules at all, but rather short-lived complexes of independent atoms. But some dynamical considerations support the molecular designation. First, there is the observed experimental resolution. The widths of the resonant peaks are on the order of 5-10 MHz, which suggests that the structure lasts typically more than 10 ns. The frequency spacings between bound states of the 0_u^+ well range from tens to hundreds of MHz and relate roughly to the frequencies of molecular vibration. Thus, there is indeed time for many oscillations of the long-range dimer. In addition, the observed oscillation frequencies do not change noticeably if a 1-mT change in magnetic field is introduced. If the spectrum had a purely atomic basis, one would expect resonance lines to exhibit large Zeeman shifts proportional to the atomic Lande g factor. The absence of such shifts suggests that a molecular interaction has overtaken the atomic magnetic dipoles and hampered their ability to remain oriented with respect to the applied field.

While the ability to produce giant dimers has been established, several questions remain. In particular, the details of the molecular decay mechanism are still under investigation. It is clear that decaying dimers deposit kinetic energy into the trapped atomic cloud, but not much is known about the decay products (atoms and/or ions) that transfer the energy through collisions. One hint may come from photoassociation experiments in the group of Peter van der Straten at Utrecht, in which the ion production in a He* MOT is monitored. Whereas several molecular resonance lines are observed, none of them correspond to the states of the giant dimer. This suggests that the decay of the dimer is not dominated by a process like Penning ionization, and perhaps also that the spin-conservation principle that enables evaporative cooling to work somehow still applies in the more complicated context of this molecule. Further analysis will be required before this possibility is fully understood, and many more experiments will have to be done in order to sort out the heating mechanisms in the cloud.



▲ Fig. 4: A resonant temperature increase in the trapped atomic cloud is observed when the photoassociation laser frequency is scanned across a bound state in the long-range potential well.

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Magnetic micromanipulation in the living cell

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During the diverse processes that govern the survival and development of living organisms, each cell must react continuously, in a perfectly orchestrated manner, to a variety of internal and external constraints. The mechanical properties of the cell membrane are fundamental in this respect: on the one hand, resistance to deformation allows the cell to control its shape and to resist high sheer stresses, while, on the other hand, membrane tension governs exchanges with the extracellular environment. Furthermore, all cells possess a dynamic inner cytoskeleton—a three-dimensional network composed of three sorts of protein filaments. The cytoskeleton serves as an active mechanical support for the cell body and contributes to cell shape maintenance. It controls chromosome migration during cell division, offers a "railway network" for intracellular trafficking, and contributes to the formation of membrane extrusions necessary for cell movement.

Cellular functions and physical properties (membrane rigidity and tension, cytoskeleton elasticity, cytoplasmic viscoelasticity, etc.) thus appear to be intricately related. A new challenge for the biophysicist is therefore to develop micromanipulations that mechanically deform the living cell in a controlled manner and thereby gain insights into the cellular machinery. These deformations may target the whole cell or involve local constraints applied to the cell surface. The micropipette aspiration technique is by far the most widely used method for manipulating the overall shape of individual cells [1]. This approach has been used to explore the rheological behavior of blood cells in suspension, to characterize the resistance of their membranes, and to model the mechanical responses of endothelial cells and fibroblasts. More recently, new designs were made to stretch a single cell either between two microplates to which it was adherent, or using an optical stretcher which takes advantage of the optical deformability of cells. Local perturbations can be generated on the plasma membrane by using microneedles or atomic force microscopy (AFM) probes. Finally, it is through the use of microbeads attached to the cell membrane and manipulated by means of magnetic [2] or optical tweezers that some interesting data have been obtained in recent years, notably on the transfer of forces between the inner cytoskeleton and the extracellular matrix, and the local characteristics of elastic and viscoelastic modules and the tension of the external cell membrane and cortical cytoskeleton.

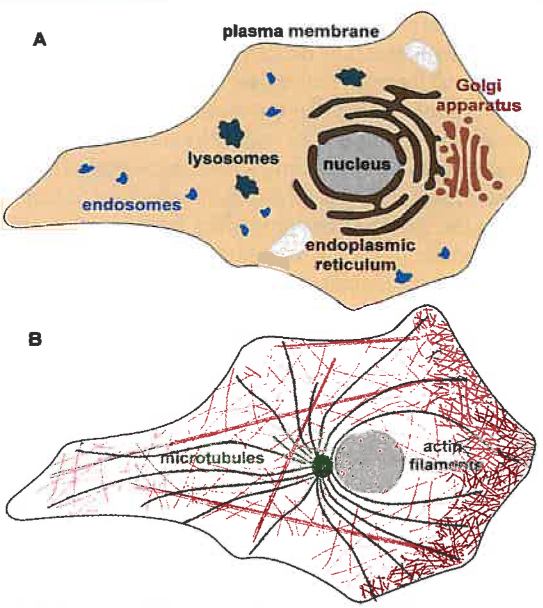
Yet even these locally applied techniques mechanically disturb the plasma membrane, potentially altering the cell machinery which itself is submitted to a variety of physiological constraints. In the 1980s the intracellular medium started to be considered as a viscoelastic matrix contributing to cytoplasmic organization, cell movements, intracellular exchanges, and cell shape. Biophysical methods available to probe the local organization of the intracellular environment remain rare, however, because of the experimental difficulties inherent in introducing a probe into a living cell and manipulating it in a "non invasive" manner. Two principal approaches have been developed. The first approach (passive microrheology without external force application, see box 2) involves studying the spontaneous displacement of intracellular granules [3] or internalized microbeads [4] in order to deduce local rheologic properties. In the second approach (active microrheology, see box 2), magnetic microbeads engulfed by macrophages are submitted to a magnetic force or couple, and their response offers information on the viscoelastic modules of the surrounding medium [5]. However, all these approaches necessitate the used of particular cellular models (specialized cells capable of phagocytosing micron-size objects or containing readily identifiable rigid granules), meaning that current intracellular microrheology techniques cannot be applied to all cell types. Furthermore, while these methods can be used to probe the dynamics of intracellular objects or to apply precise constraints, they are unsuitable for exploring the dynamics of intracellular membranes. Yet these membranes represent 98% of the total membrane surface area of a given cell, forming enclosed aqueous compartments with specialized functions. Macromolecules are intensively trafficked between these different compartments, involving processes of mem-

Let's talk about cells

Every living organism is made of millions of millions of cells. The human body contains about 200 different types of cells which have various functions and life times. For instance, we can mention the blood cells (erythrocytes, leucocytes, ...) that circulate throughout the body via the circulatory system, the endothelial cells that form the lining of all blood vessels, the tissue cells that are the bricks of the organs, the fibroblasts associated with healing wounds and the macrophages able to recognize (and then ingest) foreigners.

The cell is a highly organized small factory (Figure 1A). The nucleus is the head office and contains the DNA which carries the genetic information. The plasma membrane is fencing the cell. The space between the nucleus and the plasma membrane is called the cytoplasm. In the cytoplasm can be found the cell specialized sub-units called organelles. For instance, the endoplasmic reticulum organelle is the production center for proteins and lipids which are then addressed to the sorting center, the Golgi apparatus. Internalization of small materials (<0.1μm) through the cell plasma membrane is called the endocytosis. When larger materials (1μm or more) enter the cell, the process is called the phagocytosis. Organelles known as endosomes (in the case of the endocytosis) or phagosomes (in the case of phagocytosis) conveys the newly ingested materials and delivers them to other organelles where they will be used. Unuseful materials are sent to the organelles called lysosomes which are the cell waste centers.

The cell has a structure which could appear as a mixture of a skeleton and a musculature (Figure 1B). This structure is called cytoskeleton and gives the cell its shape, cohesion, ability to move and internal organization. The cytoskeleton is composed of a dense network of protein filaments. Its most important components are actin filaments and microtubules. Both are involved in shaping the cell. Moreover, actin filaments are essential to the movement generation, enabling the cell to crawl, whereas microtubules are the cell conveyer belts, enabling intracellular transport. This cytoskeleton confers to the cell outstanding mechanical properties. In particular, the cell content appears as a viscoelastic body, meaning it is at the same time a viscous liquid and an elastic solid.



▲ Fig. 1: (A): The cell and its organelles. (B): The cell cytoskeleton.

brane fusion, fission and budding, and this is crucial for cell survival. Each membrane compartment possesses a specific lipid and protein composition conferring the mechanical properties required to support these dynamic exchanges. Hence characterizing the mechanical properties of these intracellular membranes appears fundamental. However, while plasma membrane tension and deformation have been widely studied, there has as yet been no way of constraining or deforming intracellular membranes in a controlled manner.

We have developed a new method designed to apply, both locally and non invasively, mechanical constraints inside the living cell. We use anionic magnetic nanoparticles which, thanks to their spontaneous interaction with the outer cell membrane, follow the endocytosis pathway and become concentrated in pre-existing intracellular membrane-bound vesicles known as endosomes. This renders these compartments magnetic, and allows them to be manipulated within the cytoplasmic environment by applying an external magnetic field. A precise constraint can thus be applied to the endosome itself or to its microenvironment. This enables us not only to deform the endosome membrane and thereby to deduce its bending stiffness and resting tension, but also to form small chains of magnetic endosomes whose dynamic behavior in the externally applied magnetic field reflects the intracellular architecture. This is, to our knowledge, the first time one could deform in living cell intracellular organelles. Besides the magnetic endosome appear for now as the unique probe that can be obtained in any living cell to explore the local mechanical properties of the cell intracellular microenvironment. The originality and biological relevance of this magnetic probing method lie in the fact that endocytosis is used by all cells to communicate with their environment.

Endocytosis of magnetic nanoparticles [6]

We first showed that, after adsorbing to the cell membrane, anionic magnetic nanoparticles are trafficked to intracellular compartments via the endocytosis mechanism used by cells to internalize extracellular substances. Figure 2 shows the different steps of nanoparticle endocytosis, as seen under the electron microscope. The electron-dense nanoparticles appear as small black spots. They begin by attaching to the cell membrane in small aggregates (figure 2a). A portion of the membrane then invaginates (figure 2b) to form a membrane-bound vesicle less than 100 nm in diameter, which moves into the intracellular space (figure 2c). The vesicle then releases its contents into preformed membrane compartments (endosomes), in which the nanoparticles gradually accumulate (figure 2d). Each of these "magnetic endosome" forms an ideal probe for intracellular magnetic micromanipulation.

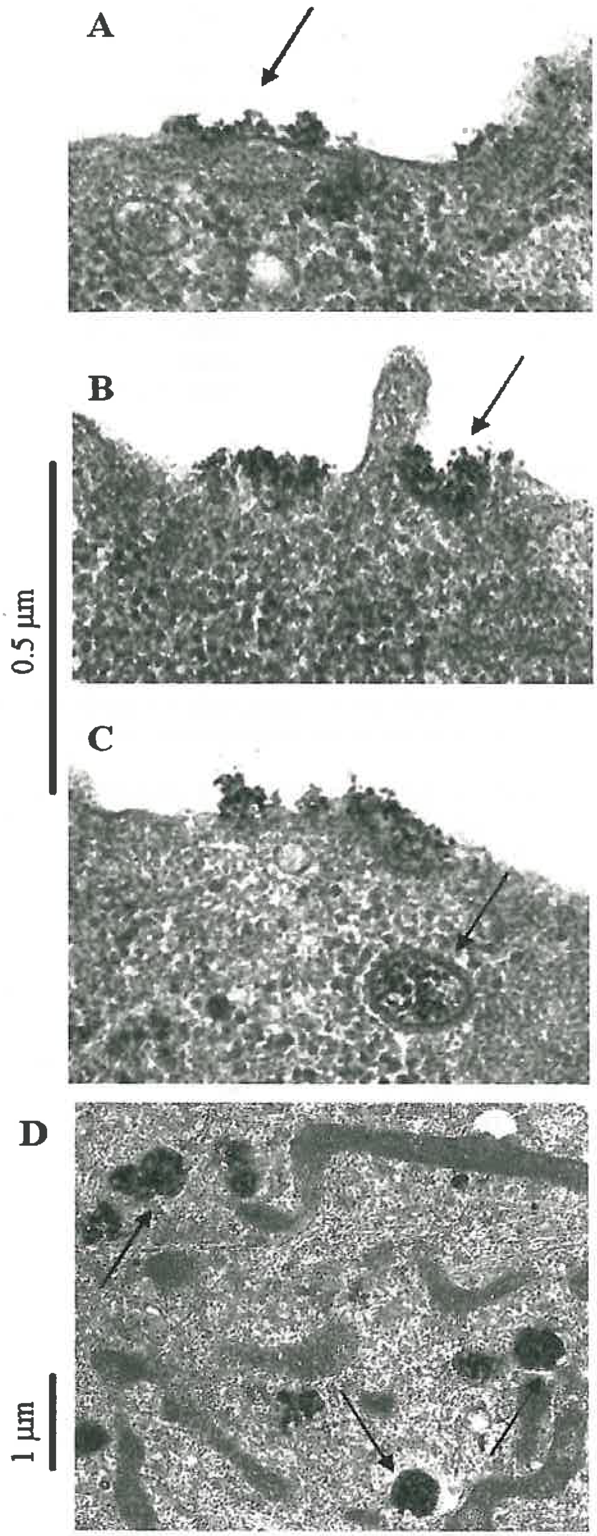
Controlled intracellular membrane deformation [7]

By using this approach we were able to apply controlled constraints to intracellular membranes of a living cell, for the first time to our knowledge. Magnetization of the fluid contents of the endosome deforms the endosome along the direction of the applied field, under the influence of magnetic surface force effects. Only electronic microscopy can reveal the structure and morphology of the membranes of these submicronic compartments. Figure 3a shows nanoparticle-loaded endosomes that have not yet been submitted to a magnetic field. The contours of the endosome are undulated, showing that the membrane is flexible and flaccid. If we could film these endosomes, we would see their membranes agitated by thermal fluctuations and exploring different shape configurations. Under the effect of a uniform magnetic field (see figure 3b), the endosome appears to elongate in the direction of the field, while conserving a wavy, irregular membrane. To quantify this deformation, we averaged a large number of instantaneous shapes, each representing a different state of fluctuation. Figure 3c shows, for several different magnetic field intensities, the contour of the averaged endosome, superposed on the merged image of all the shapes analyzed. In zero field conditions the averaged contour is a circle; in other words the endosome is isotropic. Under a magnetic field, the averaged endosome gradually turns into a prolate ellipsoid whose long axis matches the direction of the magnetic field. The deformation of the endosome membrane is then perfectly described in terms of the reduction in membrane undulations. We were thus able to demonstrate that endosomes appear to be flaccid with significant resting tension (compared to plasma membrane), but low bending stiffness. This important resting tension will probably trigger fusion events, whereas the low bending stiffness should be related to the peculiar protein-lipid composition of endosomal membranes.

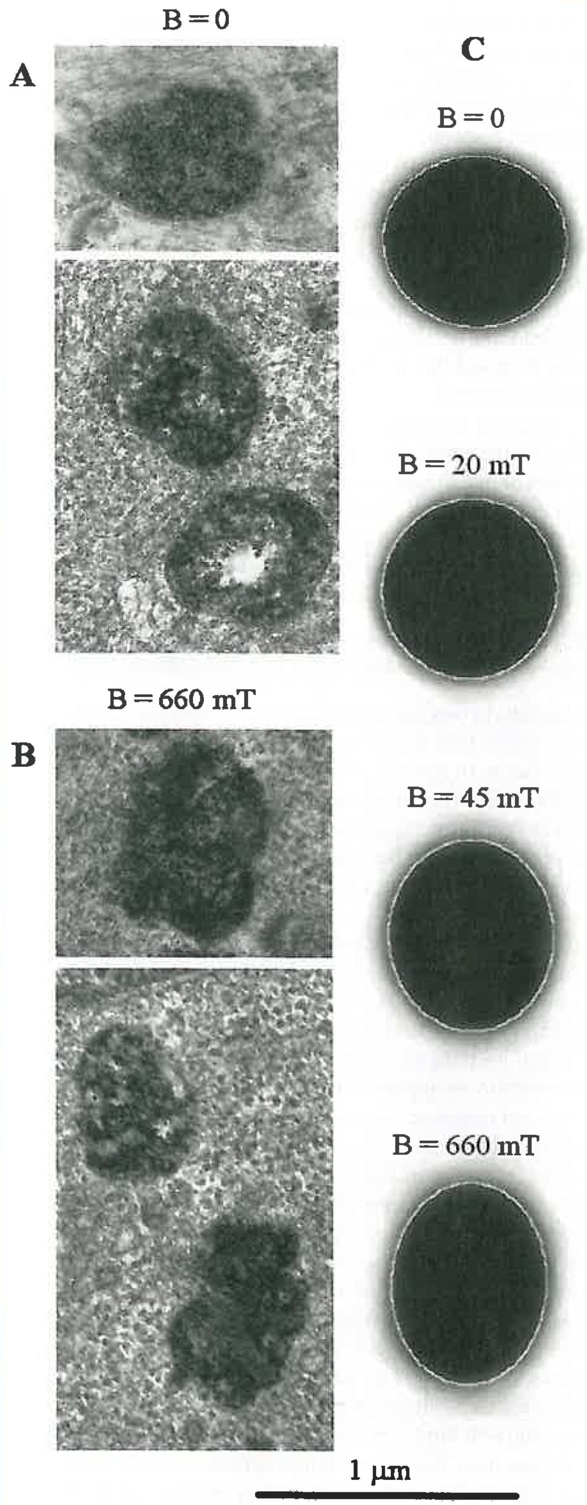
Viscoelastic architecture surrounding endosomes [8]

These magnetic endosomes also interact with one another under the effect of the dipolar magnetic force, forming small cohesive chains inside the cell (figure 4a). We were able to make these chains of magnetic endosomes rotate, and could thereby obtain information on the viscoelastic properties of their microenvironment after developing a new microrheology technique (see box 2). In this way we could map intracellular viscoelasticity within the vicinity of magnetic endosome chains located in various parts of the cell. We found that viscoelasticity in the vicinity of endosome chains situated close to the nucleus resulted from close cooperation between the different networks of cytoskeleton filaments (microtubules and actin filaments): viscoelasticity was high in untreated cells, and fell to a similar extent when one of the filament types was selectively depolymerized. Viscoelasticity in the vicinity of chains located some distance from the nucleus was about one order of magnitude lower and did not depend on the presence of microtubules or actin filaments.

The probed cellular architecture depends closely on the biological nature of the probe. Endosome mobility between the plasma membrane and the perinuclear region is crucial for all recycling and degradation pathways. In keeping with our measurements, mobile endosomes must move in a weakly viscoelastic environment.



▲ Fig. 2: Electron micrographs showing (black arrows): (A) adsorption of magnetic nanoparticles (black spots) to the cell outer membrane; (B-C) the first steps of endocytosis: membrane invagination and formation of early vesicles; (D) subsequent formation of micronic intracellular compartments (late endosomes and lysosomes) containing abundant nanoparticles.



▲ Fig. 3: Subcellular magnetic micromanipulations. (A): Electron microscopic studies of the undulating nature of the magnetic endosome membrane when no magnetic field is applied. (B): Under the effect of a magnetic field (B), the endosome membrane remains irregular and wavy, while the endosome elongates in the direction of the field. (C): Quantification of the deformation: averaged shape of endosomes at different intensities of applied field B.

In contrast, endosome mobility is reduced in the perinuclear region by a dense viscoelastic matrix created by the two subnetworks of actin and microtubules. Both types of filament thus appear to be involved in stabilizing late endosomes and lysosomes in the perinuclear region, thereby facilitating fusion events and regulating the degradation pathway.

These studies are part of broader investigations of local and global cellular responses to mechanical constraints. Much current work is based on applying mechanical constraints to the whole cell or to its membrane, while methods allowing constraints to be applied locally and non invasively inside a living cell are still in their infancy. Our initial experimental micromanipulations of intracellular organelles should lead to a better understanding of intracellular dynamics by offering the possibility to modulate physical parameters that control biological activities:

-Resistance to deformation of membranes of compartments involved in the endocytosis pathway may contribute to controlling exchanges of macromolecules and lipids between the different intracellular compartments. These exchanges indeed require membrane fusion/fission, and budding/fusion of vesicles with the membranes of the different compartments—processes that are dependent on the mechanical properties of the membranes concerned.

Rotational microrheology

In classical rheological approaches the sample is macroscopically perturbed by a controlled constraint or an imposed deformation. In new microrheology techniques developed over the last decade the sample is deformed locally by the displacement of micron-scale probes. These techniques can be used to study the rheological behavior of living cells (volume about 10^{-5} mm^3). Two complementary approaches have proven particularly useful:

1. "Passive" techniques based on the observation of the Brownian movement of probing beads dispersed in a fluid. Rheological properties are deduced indirectly by applying the fluctuation–dissipation theorem.
2. "Active" techniques use the translational response of micron-scale beads to an applied force. The force is produced either by an external magnetic field (magnetic tweezers) or by a focalized laser (optical tweezers). Our rotational microrheology technique involves the use of an active rotating probe. The use of translated probes encounters problems when the probe is very small: applied magnetic or optical forces proportional to the probe volume must counteract viscoelastic forces that depend only on the probe diameter. In contrast, rotational dynamics depend only on the aspect ratio of the probe.

We first developed local macroscopic probes in translation (magnetic beads 1 mm in diameter) and in rotation (nickel needles 0.5 mm long) in order to compare their dynamics within a linear Maxwell fluid. The use of a rotating probe to deduce the viscoelasticity of the surrounding medium was fully validated in these experiments, and we then used a microscopic probe consisting of chains of magnetic 650nm-diameter particles, in the same viscoelastic fluid. Two types of measurements were made to validate and calibrate the measurement of viscoelasticity at the microscopic scale, namely a global measurement (based on light diffusion) of the frequency response of the particle chains to an oscillating magnetic field; and a local (microscopic) measurement of the response of a chain to the field. It is the second approach that we adopted to mechanically probe the interior of living cells.

Quantification of the spatial organization of actin filaments and microtubules would throw light on the cooperation between these two polymer types and their role in intracellular dynamics. The magnetic endosome can be considered both as a probe inserted within a viscoelastic matrix whose properties reflect local polymer organization, and as an effector interacting with cytoskeleton components through associated molecular motors. Thus, movements of endosomes piloted by an external magnetic field could offer signatures of specific molecular mechanisms.

The magnetic endosome is an innovative tool for probing the properties of intracellular membranes and biological polymers that form the intracellular matrix. This approach may offer answers to questions on the intracellular transport, on the mechanisms underlying exchanges between compartments of the endocytosis pathway, and on the cooperation between cytoskeleton component filaments.■

About the authors

Jean-Claude Bacri is professor of Physics at the University Paris 7 since 1985 and is head of a research group concerning physical properties of magnetic colloids (ferrofluids). He is one of the most knowledgeable ferrofluid researcher in ferrohydrodynamics.

Florence Gazeau and **Claire Wilhelm** received their phD in Physics in 1997 and 2002 and are researchers at Centre National de La Recherche Scientfique (CNRS) since 1998 and 2003, respectively. They are developping biomedical applications of magnetic nanoparticles for cell mechanics, cellular imaging (using MRI) and tumor therapy.

Jean-Claude Bacri, Florence Gazeau and **Claire Wilhelm** have joined the group "Physique du Vivant (Physics of Life)" of the laboratory "Matière et Systèmes Complexes" of the University Paris 7 (CNRS, UMR7057).

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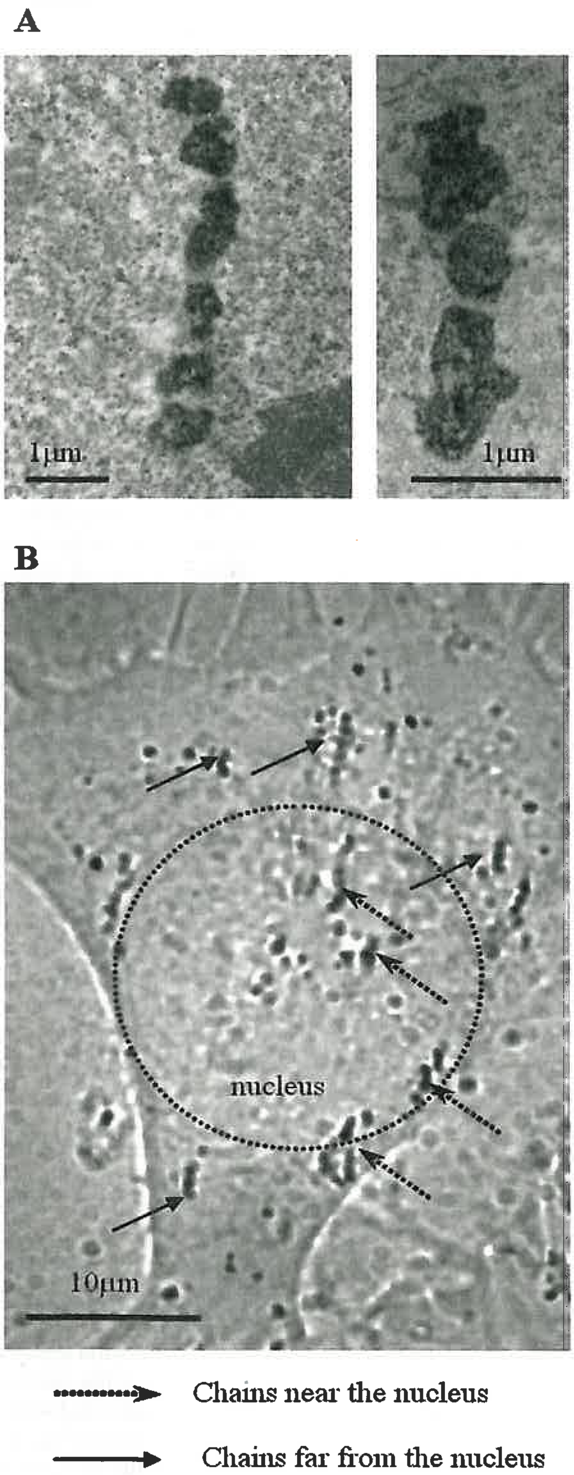

▲ Fig. 4: Subcellular magnetic micromanipulations. (A): Electron micrographs of chains of magnetic endosomes formed in a magnetic field of 150 mT. (B): Light micrograph of magnetic endosome chains inside a living cell. Local viscoelasticity can be deduced from the rotational behavior of the chains piloted by an external magnetic field. Chains of endosomes located close to the nucleus are "stuck" in a dense viscoelastic matrix, while viscoelasticity is markedly lower at a distance from the nucleus.

Science and the Miracles of Exodus

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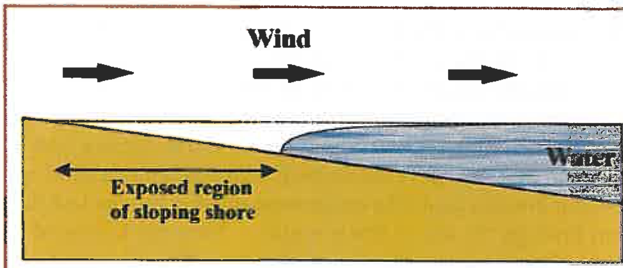
Did Moses and the Israelites really cross the Red Sea? If so, can physics explain how? Is it physically possible to obtain water from a rock? Is there a scientific mechanism underlying the crossing of the River Jordan? How can a mountain like Mount Sinai emit a sound like a trumpet? At first sight, these miracles in the biblical story of the Exodus of the Israelites from Egypt over 3000 years ago seem incredible. Because they appear to violate the normal running of the natural world, many scientists are sceptical that they could have happened. However, is it true that the well-known miracles mentioned above violate the normal running of the natural world? In this article I will take a closer look at some of the Exodus miracles through the eyes of a scientist.

Water from a rock

The miracle of obtaining water from a rock is described in just two verses in the Old Testament book of Exodus: "The Lord said to Moses 'Take in your hand the staff with which you struck the Nile, and go. I will stand there before you by the rock at Horeb. Strike the rock, and water will come out of it for the people to drink.' So Moses did this in the sign of the elders of Israel" (Exodus 17:5-6).

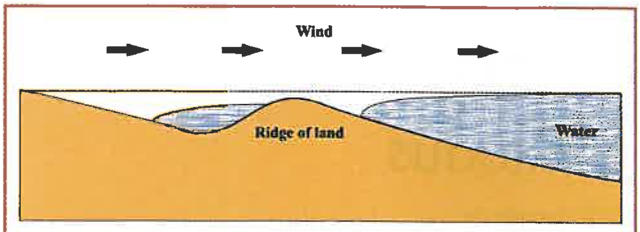
What a curious incident! Obtaining water from a rock would seem to be like obtaining blood from a stone: impossible. But let us look more closely. The Hebrew word used for "strike" in "strike the rock" implies a heavy blow: so Moses gave the rock a good thump. For a rock to give out water it has to be able to store water, so it has to be porous. Do porous rocks exist? The answer is yes, and porous rocks like sandstone and limestone can absorb huge quantities of water from rain. In fact, when they are underground we use them as aquifers, natural reservoirs of water, and we sink wells and boreholes into them to extract the water.

If porous rocks, such as sandstone and limestone, are above ground, rainwater isn't normally stored in them: it flows out through the pores. However, in a desert region, rocks weather in an unusual way because of sandstorms, which at high speed sweep sand and organic matter from decaying plants and animals on to the rocks. Over time, porous rocks in a desert can develop a hard impervious crust, rather like cement, due to this weathering.



▲ Fig. 1: Diagram of wind setdown. The water is blown back, exposing a region of sloping shore (normal waterline drawn dotted).

features



▲ Fig. 2: Water on both sides of a ridge of higher land. Normally the ridge is submerged below the waterline (dotted)

Modern Bedouin call this hard crust "desert varnish", and it provides a smooth surface for their rock art. If the crust of a porous rock is broken by a sharp blow, water can indeed flow out, and this is an effect that is well known to geophysicists working in desert regions.

There is an interesting account of obtaining water from a rock in *Yesterday and Today in Sinai* written in 1936 by a former British governor of the Sinai Peninsula, Major Jarvis . He writes: "The striking of a rock by Moses and the gushing forth of water sounds like a veritable miracle, but the writer [Major Jarvis] has actually seen it happen. Some of the Sinai Camel Corps had halted in a wadi [a dried up river stream] and were digging in the loose gravel accumulated at one of the rocky sides to obtain water that was slowly trickling through the limestone rock. The men were working slowly and the Colour Sergeant said "Give it to me" and, seizing a shovel from one of the men, he began to dig with great vigour. One of his lusty blows hit the rock, when the polished hard face that forms on weathered limestone cracked and fell away, exposing the soft porous rock beneath, and out of the porous rock came a great gush of clear water. It is regrettable that the Sudanese Camel Corps hailed their Non-Commissioned Officer with shouts of: "What ho, the prophet Moses!"

Physicists at NASA utilised their knowledge of a hard crust forming on rocks in a desert in their search for water on Mars. For example, an Associated Press report dated 25 February 2004 states: "NASA Rover Drills Martian Rock for Water. The six-wheeled Rover used the rock-abrasion tool on its instrument-tipped arm to grind a fraction of an inch into the surface of a rock called "El Capitan." The rock's weathered surface was ground away, so that the Rover could examine the material underneath."

We have seen that Moses obtaining water from a rock violates no physical laws. The biblical story fits what we know from science. So was the event a miracle? I will discuss this later, after we have looked at some other Exodus miracles through the eyes of a scientist.

Crossing the Red Sea

Moses and the Israelites crossing the Red Sea is one of the best-known miracles in the Bible. The miracle is essentially in two parts. First, the sea is driven back and the Israelites cross on dry land. Then, the sea comes rushing in and the Egyptians pursuing the Israelites are drowned. This is how the Bible describes these events: "Then Moses stretched out his hand over the sea, and all that night the Lord drove the sea back with a strong east wind and turned it into dry land. The waters were divided and the Israelites went through the sea on dry ground ... Then the Lord said to Moses, 'Stretch out your hand over the sea so that the waters may flow back over the Egyptians and their chariots and horsemen' ... The water flowed back and covered the chariots and horsemen – the entire army of Pharaoh that had followed the Israelites into the sea (Exodus 14: 21-22, 26-28).

The water of the Red Sea retreating and then rushing back may bring to mind the tsunami that devastated parts of Asia at the end of 2004. A number of people have in fact proposed that the crossing of the Red Sea was made possible by a tsunami, which resulted from the eruption of the volcano Santorini, a Greek volcanic island in the Mediterranean. However, we can dismiss this idea because the eruption of Santorini occurred well before the events of the Exodus. In addition, although a tsunami frequently causes the sea to retreat before it rushes in, the retreat only lasts for a few minutes, as was the case in the recent Asian tsunami. A few minutes would not have given thousands of Israelites sufficient time to cross the Red Sea.

A further suggestion is that the crossing was made possible by a very low tide followed by a very high tide. However, although in some locations in the world the tide can come in rapidly because of how the land lies, and people can be trapped and drowned, this is not the case in the Red Sea and its two branches, the Gulf of Suez and the Gulf of Aqaba, where the tide comes in slowly.

So if there is a natural explanation of the crossing of the Red Sea, it has to be different from those given above. In fact the biblical description is explicit that there was indeed a natural mechanism: a strong east wind that blew all night. A wind blowing along the surface of a body of water exerts a stress on the water which forces it back. If the water is on a sloping shoreline then the wind can force the water back and expose hundreds of metres of shore. Oceanographers call this "wind setdown." If the direction of the wind is reversed, the water is forced higher up the shore and this is called "wind setup." An alternative name sometimes used for wind setdown or setup is wind tide.

The physics of wind setdown and setup involves second order differential equations. The solution of these equations shows that the effect is only appreciable if the wind blows along a long stretch of water, which increases the total force on the water, and if the wind blows for a long time, because the water is slowly blown back. In a typical situation, a steady state is reached, when the water is blown back a maximum distance, only after the wind has been blowing for a number of hours. It is interesting to note that the Bible says that a strong east wind blew *all night:* just what is required for appreciable wind setdown. Wind setdown effects can be surprisingly large. For example, a strong wind blowing along Lake Erie, one of the Great Lakes, has produced water elevation differences of as much as five metres between Toledo, Ohio, on the west and Buffalo, New York, on the east.

Various sites for the Red Sea crossing have been proposed, including inland lakes and the Gulfs of Suez and Aqaba. If the physical mechanism which enabled the crossing was wind setdown then we can rule out the inland lakes in the Sinai Peninsula, because they are not long enough for appreciable wind setdown to occur. This leaves the Gulfs of Suez and Aqaba as the only possibilities, both of which are long enough for large wind setdown effects. (There has been much debate on the meaning of the Hebrew words translated "Red Sea", whether the term refers to inland lakes, or to the Red Sea and its two gulfs, or to all of these. For a detailed discussion see my book *The Miracles of Exodus*).

Since the book of Exodus refers to a strong east wind that blew back the waters of the Red Sea, I believe we can rule out the Gulf of Suez (since an east wind would blow *across* this gulf and not *along* it), leaving the Gulf of Aqaba as the only possibility. I have shown (see *The Miracles of Exodus* for details) that a very strong wind could push back the sea at the head of the Gulf of Aqaba for about 800 metres. Interestingly, the mathematics show that the water that is pushed back rises up vertically from the seabed at the receding point, just like a wall (see figure 1). The book of Exodus states: "By the blast of your [God's] nostrils the waters piled up. The surging waters stood firm like a wall" (Exodus 15:8). The Bible also refers to "a wall of water on their [the Israelites] right and on their left" (Exodus 14:22). This is more difficult to explain, but one possibility is due to a ridge of land as shown in figure 2.

At figure sight, the drowning of Pharaoh's army is more difficult to understand than the Israelites crossing of the Red Sea on dry land. Why didn't the Egyptian army see the water of the Gulf of Aqaba flowing back towards them and escape? The clear implication of the Exodus account is that there wasn't time.

What happens if a strong wind blows for a number of hours, producing appreciable wind setdown and then suddenly stops, which is the implication of the Exodus account? The mathematics shows that the water returns as a fast-moving vertical wave called a "bore". I have performed some calculations for the Gulf of Aqaba, and the speed of the returning bore wave is about five metres per second: sufficient to knock over a horse and its rider and hurl them into the sea. So the natural mechanism of wind setdown followed by a wall of water rushing back in fits well the description of events in the book of Exodus.

The sound of a trumpet from Mount Sinai

Perhaps the most controversial aspect of my book *The Miracles of Exodus* is that I believe Mount Sinai was a volcano. I am not the first to suggest this, but I have come up with some new insights from physics which further supports the volcano theory.

The most obvious signs that Mount Sinai was a volcano are the clouds and fire on the top: "You came near and stood at the foot of the mountain [Mount Sinai] while it blazed with fire to the very heavens, with black clouds and deep darkness (Deuteronomy 4:11). What a vivid description of an erupting volcano!

The book of Exodus also refers to lightning: "On the morning of the third day there was thunder and lightning, with a thick cloud over the mountain [Sinai]" (Exodus 19:16). Lightning occurs in some volcanic eruptions for a good physical reason: the ash particles emitted are charged and huge potential differences build up in an eruption cloud, which then discharges as bolts of lightning.

Intriguingly Exodus refers to the sound of a trumpet coming from Mount Sinai: "On the morning of the third day there was thunder and lightning, with a thick cloud over the mountain with a very loud trumpet blast ... the sound of the trumpet grew louder and louder" (Exodus 19: 16-19). How can a mountain produce a sound like a trumpet blast? Molten volcanic rock, called magma, contains dissolved volcanic gases, such as water vapour and carbon dioxide. If these gases are forced out through cracks in the rocks surrounding the erupting hot zone of a volcano, then the sound of a loud trumpet blast can indeed sometimes be heard. (A normal trumpet blast is similarly produced by blowing air at high speed into a trumpet). The Roman historian Dio Cassius reported that the sound of trumpets was heard coming from Vesuvius in its famous eruption in AD79.

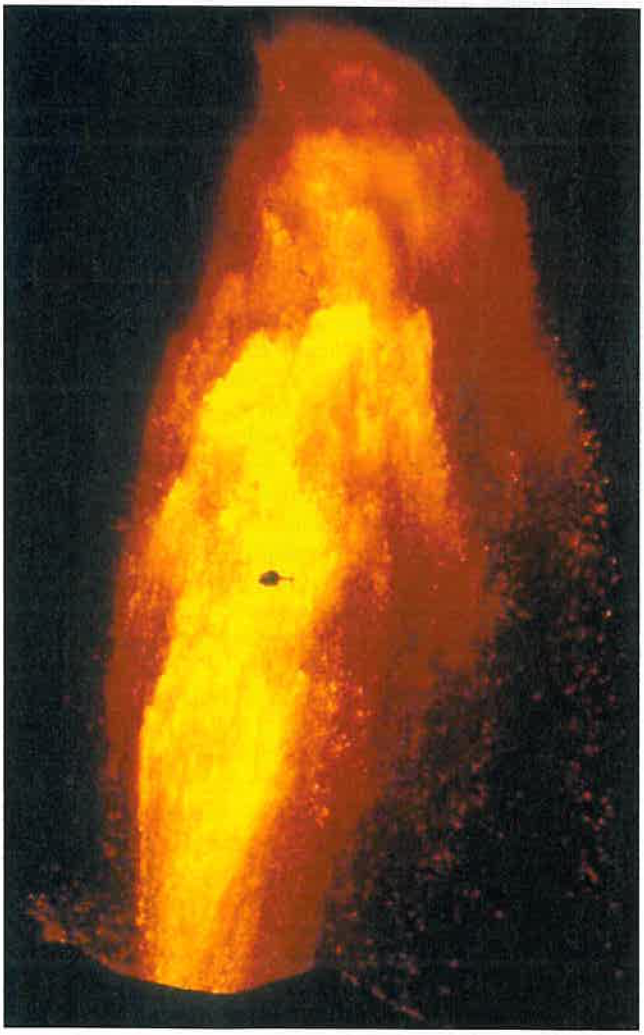
It is clear from the physics involved that if the "sound of a trumpet" is heard coming from a mountain, then that mountain is a volcano. In fact in its description of Mount Sinai the Old Testament gives no fewer than six characteristic features of a volcano: (1) it blazed with fire to the very heavens (Deuteronomy 4:1), see fig 3; (2) smoke and clouds billowed up from it (Deuteronomy 4:11 and Exodus 19:18), see fig 4; (3) the noise of explosions – an explosive eruption (Exodus 19:16); (4) a very loud trumpet blast – the sound made by hot gases escaping through cracks in the rocks (Exodus 19:16); (5) lightning – electrical discharges in the eruption cloud (Exodus 19:16); (6) volcanic earthquakes – the whole mountain trembled violently (Exodus 19:18). Here we have a remarkable description of an erupting volcano based on careful observations.

There are no volcanoes that have been active in the last 10,000 years in the Sinai Peninsula or Egypt. For this reason, and others, I believe Mount Sinai is in Saudi Arabia, which does have historically active volcanoes, in particular that it is the volcanic Mount Bedr, which fits the biblical description of Mount Sinai impressively well.

The Pillar of Fire and Pillar of Cloud

The mysterious pillar of fire and pillar of cloud that guided the Israelites to Mount Sinai have long puzzled scholars. Here is what the book of Exodus says: "By day the Lord went ahead of them in a pillar of cloud to guide them on their way and by night in a pillar of fire to give them light, so that they could travel by day or night. Neither the pillar of cloud by day nor the pillar of fire by night left its place in front of the people" (Exodus 13: 20-22).

The traditional interpretation of the pillars of cloud and fire is that these pillars were just in front of the Israelites and that they moved with them as they marched, rather like tour group leaders holding up a rolled umbrella and walking at the head of the group. But the book of Exodus does not imply that the pillars of



▲ Fig. 3: A pillar of fire by night, from a volcano in Hawaii

features

cloud and fire were just in front of the Israelites, and neither does it state that they were moving pillars; they could have been a considerable distance ahead and fixed, like a beacon on a hill giving light.

There is, in fact, a natural event that fits perfectly the description "pillar of cloud by day and pillar of fire by night": a volcanic eruption. Why does a volcano often appear to emit cloud by day and fire by night? Physics provides the answer. In a volcanic eruption huge towering flames leap out of a volcano surrounded by thick clouds of vapour. By day, often only the surrounding cloud is visible, reflecting the light of the sun. But by night the cloud is invisible and the volcanic fire becomes visible. Similarly in a smoky bonfire seen from a distance, by day you see mainly the smoke and by night mainly the flames. Figures 3 and 4 show a typical pillar of fire by night and pillar of cloud by day emitted by a volcano.

Madame Louise Vigée-Lebrun, who had painted Queen Marie Antoinette's portrait, emigrated to Italy at the start of the French Revolution. In a letter she wrote: "Now I must tell you of my various expeditions up Vesuvius ... Then night came on, and the smoke was transformed into flames, the most beautiful sight imaginable." So once again we have smoke by day and fire by night.

Since I have identified Mount Sinai as the volcanic Mount Bedr in Saudi Arabia, it clearly makes sense for the erupting volcano that produced the pillars of cloud and of fire to be none other than Mount Sinai itself, since the purpose of the pillars was to guide the Israelites to Mount Sinai. Mount Sinai was therefore the guiding light drawing the Israelites to itself, like a mountain with a fiery beacon on its summit.

Were the Exodus miracles really miracles?

In this article I have suggested how science can explain some of the miracles in the Exodus story. In my book *The Miracles of Exodus* I give scientific explanations of some other Exodus miracles (for example, crossing the River Jordan, the burning bush, the ten plagues of Egypt and turning bitter water sweet). Do these scientific explanations mean that the miracles of the Exodus story were not really miracles and rule out the supernatural? Europhysics News is not the place for a detailed discussion of this, but let me give a few brief comments. First, the fact that we can explain an event in terms of physical mechanisms does not mean that we have explained it away. Physics can explain how all the notes in Beethoven's Pastoral Symphony are produced, but that does not mean that physics has explained why it is great music, nor that physics has eliminated the need for an expert composer.

Many years ago Aristotle wrote about miracles and he said that the "efficient cause" of a miracle could be a natural agent, with the "final cause" being the will of God. The miracle is revealed by the extraordinary timing of the event. I believe that the "efficient cause" in many of the Exodus miracles was a natural agent (a porous rock, a strong wind, a volcano, etc.) and that science can discover this natural agent and give the mechanism of the miracle. Indeed, as we have seen, the Bible is explicit that the crossing of the Red Sea was enabled by a natural agent, a strong east wind.

Although the water from the rock event was not particularly time critical, the biblical description of the Red Sea crossing was: the Egyptian army had trapped the fleeing Israelites and was about to take them back into captivity. Of course, the Red Sea being driven back by a strong wind at just the right time to save the Israelites could have been lucky chance. However, in the Exodus story we have event after event occurring at just the right time. If we accept the Old Testament description, then the timing of these events does seem to be extraordinary and that is why I suggest the events of the Exodus described here and in my book were miracles, even though science can explain them: they were miracles of timing. ■

About the author

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Further reading

Further details of the miracles described in this article, other Exodus miracles, the date of the Exodus, the number of people involved, etc., are given in *The Miracles of Exodus – a Scientist's Discovery of the Extraordinary Natural Causes of the Biblical Stories* by Colin Humphreys - Harper San Francisco (USA) and Continuum (UK) 2003 (hardback) and 2004 (paperback).

▲ Fig. 4: A pillar of cloud by day, from an erupting volcano

Comprehensive measurement and analysis of spallation in 1AGeV ^{238}U on protons

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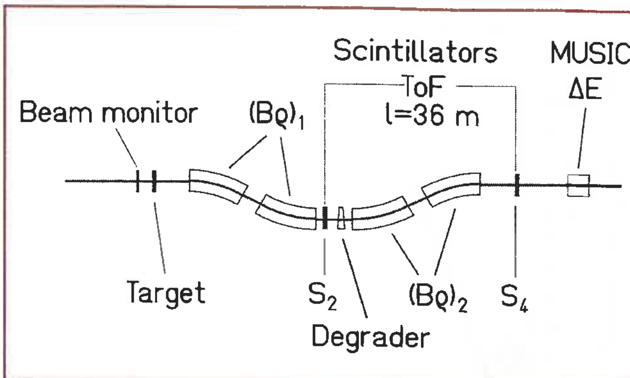
IPN-Orsay/CNRS-IN2P3 • France

The still increasing and developing world population demands more energy. Further burning of coal, oil and gas produces still more CO^2 producing deterioration of the climate. Regardless, oil and gas will run out in the middle of the century. Planning a decent future with a minimum supply of energy for those who will follow us, requires a re-examination of all possibilities of non-polluting, renewable, and sustainable energies including nuclear options. There are two nuclear reactions, which allow for a long-term exploitation: 1) converting H into He by fusion or 2) converting ^{238}U and ^{232}Th into ^{239}Pu and ^{233}U to be burnt by fission. In this paper, the fission option is the target. The real long-term reserves of fission energy lie in the even-even isotopes ^{238}U and ^{232}Th, as the supplies of ^{235}U, just like fossil fuels, are restricted, as well. The remaining ^{235}U and available ^{239}Pu could be burnt in a 3rd generation of reactors (EPR) using mixed U/Pu-fuel (MOX). Aiming at a contribution of fission energy to the world electricity production of one third, that is three times more nuclear power than today, reactors of a 4th generation should be envisaged, ready to offer wide technological applications in the middle of the century. Such an option should be foreseen as a necessary implement of a peaceful future.

Discussed in this scenario are improved systems of fast reactors, of high temperature gas-cooled reactors and of molten-salt reactors. The innovative vision for the 4th generation is Accelerator Driven reactor Systems (ADS). The nuclear waste is separated locally at the reactor sites into fissionable actinides (Th, U, Pu) to be burnt in the fuel-cycle of power reactors, and minor actinides (Np, Am, Cm) and long-lived fission products to be incinerated and transmuted in ADS. To this goal, a high intensity, 30 – 50 mA, proton beam at 1 GeV is coupled with a reactor core. The latter is run either with fast neutrons for U/Pu-fuels and minor actinides / fission products incineration or with thermal neutrons for Th/U-fuels. Two nuclear reactions are combined – spallation by protons producing cheap neutrons and nuclear fission releasing energy. Looking at the data still missing for the new systems, it is evident that spallation and fission at 1 GeV on a technological level is only poorly known. Knowledge of the chemical composition of the inventory, the material damages and the radioactivity induced by 1 GeV protons, are needed for the realisation of the spallation target of ADS.

The accelerator facility UNILAC/SIS at GSI gives access to 1 GeV beams of any stable element. A high-resolution spectrometer, the FRS, is available for investigations of reaction products. Spallation of the building materials of an ADS – U, Pb and Fe – as prototypes can be investigated in inverse kinematics. This method gives access to cross sections of almost all nuclides produced, as well as to their kinetic energies and the reaction mechanism of their production. In 1997 an experimental program was launched at GSI financed by the EU to provide data for the proposed prototype materials. A high accuracy aiming for a 10 % uncertainty in the isotopic cross sections of all elements is demanded for ADS-technology.

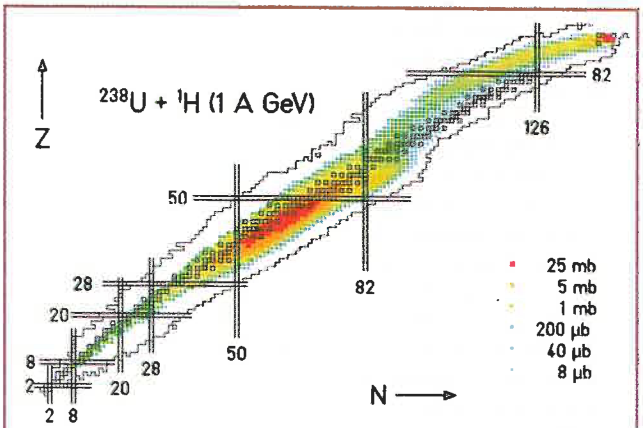


▲ Fig. 1: Schematic layout of the fragment separator FRS with the detector equipment.

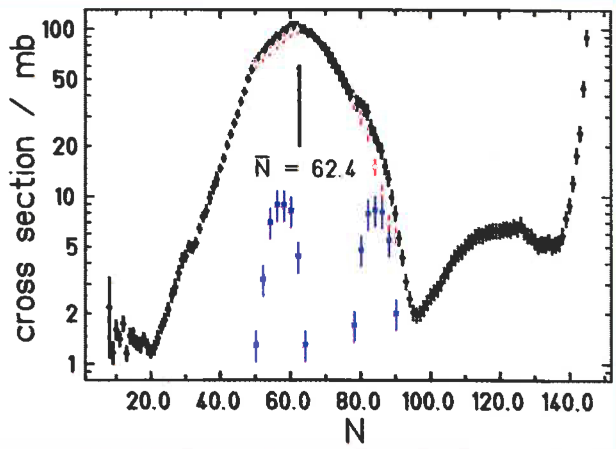
In this article, we report on the campaign dedicated to the studies of spallation reactions in inverse kinematics. Most of the experimental results have been published in scientific journals, are documented in PhD-theses, or will be published soon. A comprehensive overview of the project and the results obtained can be found in Ref. [1]. The results were obtained by physicists from IPN-Orsay/CNRS-IN2P3, France, DAPNIA /CEA-Saclay, France, the University of Santiago de Compostela, Santiago, Spain in collaboration with the physicists of the GSI, Darmstadt, Germany. (Cf photo of physicists involved.)

Experiment

The experimental method and the analysis procedure have been developed and applied in previous experiments [2,3,4]. The heavy-ion synchrotron SIS at GSI, Darmstadt, can deliver the primary beams at energies between 0.2 – 1.5 A GeV. The dedicated experimental set up is shown in Fig. 1. A liquid hydrogen target was installed Ref. [5]. Heavy residues produced in the target were



▲ Fig. 2: The 1385 identified nuclides are shown on a chart of nuclei. Numerical values are available in [9]. The magnitudes (reducing by a factor of 5) of the experimental cross-sections are indicated by a colour scale. The stable isotopes are indicated by black squares.



▲ **Fig. 3:** Measured N-distribution for all neutron numbers between N = 8 and 146. Summed cross sections (full points) from cross sections for low-energy asymmetric fission (blue squares) and for high-energy asymmetric fission (red circles) are reported separately. The minimum at N = 97 separates EVR and FF.

all strongly forward focused due to the inverse kinematics and the high velocity of the incoming beam. They were identified using the Fragment Separator (FRS) [6] and the associated detector equipment.

The FRS is a two-stage magnetic spectrometer with a dispersive intermediate image plane (S_2) and an achromatic final image plane (S_4), with a momentum acceptance of 3% and an angular acceptance of about 15 mrad around the beam axis. Two position-sensitive plastic scintillators placed at S_2 and S_4, respectively, provided the magnetic-rigidity ($B\rho$) and time-of-flight measurements, which allow the mass-over-charge ratio of the particles to be determined. For an unambiguous isotopic identification of the reaction products, the analysis was restricted to ions, which passed both stages of the fragment separator fully stripped. The losses in counting rate due to the fraction of incompletely stripped ions and the losses due to secondary reactions in the layers of matter in the beam line were corrected for.

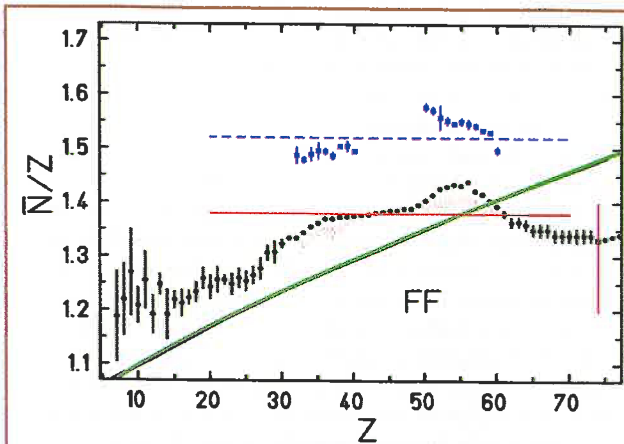
To identify all residues in the whole nuclear-charge range up to the projectile, it was necessary to use two independent methods in the analysis. The nuclear charges of the lighter elements, mainly produced by fission, were deduced from the energy loss in an ionisation chamber (MUSIC) with a resolution $Z/\Delta Z \approx 200$ obtained for the heaviest residues. Combining this information with the mass-over-charge ratio, a complete isotopic identification was performed. A mass resolution of $A/\Delta A \approx 400$ was achieved. Since part of the heavier reaction products was not completely stripped, the MUSIC signals were not sufficient for an unambiguous Z identification. Therefore, the identification of reaction products of heavier elements was performed with the help of an achromatic energy degrader [7] placed at the intermediate image plane of the FRS. Degrader thicknesses of about 5 g/cm^2 of aluminium were used. The nuclear charge of the products was deduced from the reduction in magnetic rigidity by the slowing down in the energy degrader. The MUSIC signal was still essential for suppressing events of incompletely stripped ions and from nuclei destroyed by secondary reactions in the degrader. The velocity of the identified residue was determined at S_2 from the $B\rho$ value with a relative uncertainty of $5{\cdot}10^{-4}$ and transformed into the frame of the beam. More than 100 different values of the magnetic fields were used in steps of about 2 % in order to cover all the produced residues and to construct the full velocity distribution of each residue in one projectile-target combination.

The re-construction of the full velocity distribution allows the reaction products formed in spallation and fission reactions to be disentangled due to their different kinematic properties. For isotopes produced by fission, only those emitted in a forward or backward direction with respect to the primary beam can be observed for given settings of the FRS because the angular acceptance is too small to observe sideward-emitted fragments. Isotopes produced as evaporation residues have a single narrow velocity distribution and are fully transmitted.

Reaction Mechanisms Cross Sections, and Recoil Velocities

The production of residual nuclides has been investigated for several systems, which are particularly relevant for the design of Accelerator-Driven Systems: $^{56}Fe+^{1}H$ at 0.2 - 1.5 *A* GeV, $^{208}Pb+^{1}H$ at 0.5 and 1 *A* GeV, $^{238}U+^{1}H$ at 1 *A* GeV [8]. For each system, the production rates of large numbers of final residues were measured. In the case of heavy systems, this amounts to more than a thousand nuclides per system. Moreover the velocity distributions of all these nuclides were determined. As an example, Figure 2 shows the measured production cross sections from the reaction 238U+1H at 1 A GeV [9-12] using a colour logarithmic scale. In this unique comprehensive "transmutation" of uranium, all elements from uranium to nitrogen, each with a large number of isotopes are observed. In the cross-section range down to 10 μb, 1385 nuclides are observed, as shown on the figure. The total cross-section of (1.97 ± 0.3) b divides into (1.53± 0.2) b for fission fragments (FF) and (0.44 ± 0.1) b for evaporation residues (EVR).

The spallation reaction is described as a two-step process: The collision of the fast proton on the heavy nucleus generates a cascade of nucleon-nucleon collisions in the target nucleus. Depending on the excitation energy deposited and the number of fast neutrons emitted, the remaining target nucleus gives up excitation energy by neutron-evaporation. In the process of de-excitation, the still excited nucleus can either undergo fission or continue to cool down by emitting still more neutrons. On the



▲ **Fig. 4:** The mean N̄/Z ratio plotted as a function of the atomic number. The different contributions are represented by different symbols (see Fig. 3). The valley of stability (green line) is shown. The mean N̄/Z ratio for the low-energy asymmetric process (dashed blue line) and for ^{107}Rh, representative of the high-energy process (red line), are indicated. The vertical line at Z = 74 separates fission fragments from evaporation residues.

chart of populated isotopes plotted on Fig. 2, the two de-excitation processes are well characterized. The EVR observed in the upper-right corner merge in the region of Z=73-77 with FF observed for elements below.

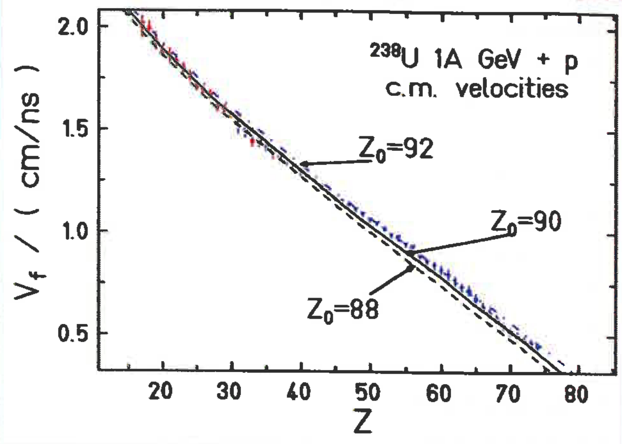
From U (red, in the upper right corner) the EVR-cross sections first fall down rapidly to N = 138 (Fig.3), covering 0.24b, the main part of the EVR cross section. Here one new isotope ^{235}Ac was discovered. The cross sections then show an extended plateau between N = 110 and N = 138 at a low level of 5.0 to 6.4 mb. At the upper limit, N = 138, highly fissionable nuclei are found being deformed and having small ground-state shell corrections. As N decreases further, spherical nuclei around N = 126 follow having large ground state shell corrections and being less fissionable. At the lower limit, N=110, fission barriers break down again and decreasing cross sections would be expected. It remains a challenge to understand the plateau of cross sections in the N-distribution. All we know about fission, level densities and their dependence on excitation energy is put to the test. At 1 GeV the excitation energy transferred in the primary cascade reaches an upper limit of about 500 MeV for a range of mass losses up to $\Delta A = 70$. The cross sections then decrease rapidly for N < 110.

The distribution of FF reveals a small (5%) contribution of the classical asymmetric low energy fission [11] as shown on Fig. 3. The underlying parent nuclei are relatively cold and cluster around ^{233}U. By subtracting the low-energy asymmetric fission, we obtain the high-energy symmetric distribution with a mean neutron number of 61.9. Combined with the mean proton number 44.9 obtained from the Z-distribution, a mean mass number of A = 106.8 is reconstructed for FF. $^{107}_{45}$Rh is the mean nuclide produced in high-energy symmetric fission.

The standard deviation of the high-energy symmetric Z- distribution of $\sigma_Z = 6.4$ a.u. is related via the curvature of the Liquid-Drop Model Potential Energy Surface (LDM-PES) to the excitation energy of the mean parent nucleus at the fission barrier [13]. With a fission barrier of 4 MeV, an energy above ground state of (58 ± 10) MeV is obtained, allowing for an emission of 6 neutrons. Adding these neutrons emitted to the neutron number of the mean pair of FF a neutron number of $N_0 = (130\pm1)$ follows for the mean parent nucleus. For high-energy symmetric fission ^{220}Th is the mean parent nucleus reconstructed from the isotopic distribution of FF. At very large asymmetries of the FF, N1/N2 < 22/102, the cross sections pass through a minimum and increase slightly for most extreme asymmetries. This was seen before [14] and is explained by the Businaro-Gallone peak in the LDM-PES beyond which fission barriers decrease again.

For the complete set of FF produced in the reaction, we obtain for each element the mean neutron to proton ratio $\overline{N}/Z$ and the width of its isotopic distribution $\sigma_N^{Z=const}$. The $\overline{N}/Z$ values are shown in Fig. 4, separated into low-energy asymmetric and high-energy symmetric fission. They describe the isospin dependence of the cross sections. The $\overline{N}/Z$ -ratio of the mean fission fragment ^{107}Rh, 1.38 (red line), is found to be smaller than for low-energy fission where $\overline{N}/Z = 1.53$.(blue dashed line)

High-energy fission shows increasing $\overline{N}/Z$ –ratios in the range Z = 34 to 56. The slope observed agrees with a charge-polarisation expected for a smooth LDM-PES showing no nuclear structure effects. A new finding is the rapid decrease of the mean neutron density for isotopes at higher asymmetries. Taking the mean parent nucleus as ^{220}Th and the most asymmetric pair observed as $Z_1/Z_2 = 16/74$, mean neutron numbers $N_1/N_2 = 19/99$ are reached that add up to 118 neutrons present in the FF. Twelve neutrons are lost that indicates a high excitation energy of about 100 MeV. This energy is distributed in the high-energy regime between the pair of FF in proportion to their masses. The heaviest elements lose up to ten neutrons, and beyond erbium, Z > 68, all isotopes observed are stable or proton-rich. Neutron-rich isotopes in the wings of the Z-distribution will come with very low cross sections for the higher elements. It is the small contribution of low-energy asymmetric fission of (105±10) mb which remains the main source of neutron-rich isotopes for elements in the range Z = 28-64 [15].



▲ Fig. 5: The mean c.m. velocity of fission fragments measured as a function of Z, the atomic number. The three lines: dashed $Z_0 = 88$, full $Z_0 = 90$, and dashed-dotted $Z_0 = 92$, are calculated assuming Coulomb repulsion with the radius constant r_0 being fixed by taking the measured value of the velocity for symmetric fission of ^{220}Th as normalisation.

Figure 5 shows the mean velocities of FF in the uranium-rest frame. A comparison with calculated velocities, indicates that a small number of elements in the range Z_0 = (88-92) dominates the family of parent nuclei. The systematic measurement of kinetic energies of spallation EVR, is achieved for the first time using our experimental method. Their kinetic energies are very small, on the average about 2.9 MeV. In this energy range slowing down of heavy ions mainly proceeds by elastic collisions.

The complete data set presented here represents the largest number of elements (from nitrogen to uranium) and isotopes (about 1400) ever observed in a single nuclear physics experiment. It is a main step forward [9], which stands for itself. Our work is not finished here. Tasks to be undertaken in the near future are open:

1) The energy dependence of the cross sections is hardly known. Further measurements at lower energies are needed for the prototype reactions selected.

2) Our data should serve as the benchmark for simulation codes of the complex physics of spallation reactions with the final goal being the prediction of intermediate systems.

3) An innovative measuring technique giving more and more precise and complete results generates a better understanding of the underlying physics. A number of surprising results are already published and can be found in our website [1].■

About the author

Monique Bernas is a physicist in experimental nuclear physics at the IPN d'Orsay, ORSAY France, bernas@IPNO.IN2P3.FR. Her lines of research are transfer reactions and fission studies aiming at unknown neutron-rich isotopes. She was involved in first investigations of ^{68}Ni and in the discovery of 107 fission products among which was the doubly magic nucleus ^{78}Ni.

features

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▲ **Fig. 6:** Members of the research team taken at the GSI experiment in 1998.
On the top row from left to right: P. Armbruster, M. Bernas, C. Stéphan, A. Brünle, F. Rejmund, T. Enqvist.
Kneeling from left to right: K. Burkard, J. Benlliure, L. Tassan-Got.

Diffraction-limited photographs

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

The optical performance of lenses, even in cheap cameras, is remarkably good these days. We don't have to worry too much about aberrations, even if we 'open up' and use the full lens aperture. Due to the steady progress in lens making over the years, our cameras – certainly the more expensive ones - are being gradually pushed to the diffraction-limited optics situation.

How does diffraction limit the resolution of our pictures? It all depends, of course, on the focal length of the lens (which we usually know) *and* the aperture, or effective lens diameter (which we may be unable to determine).

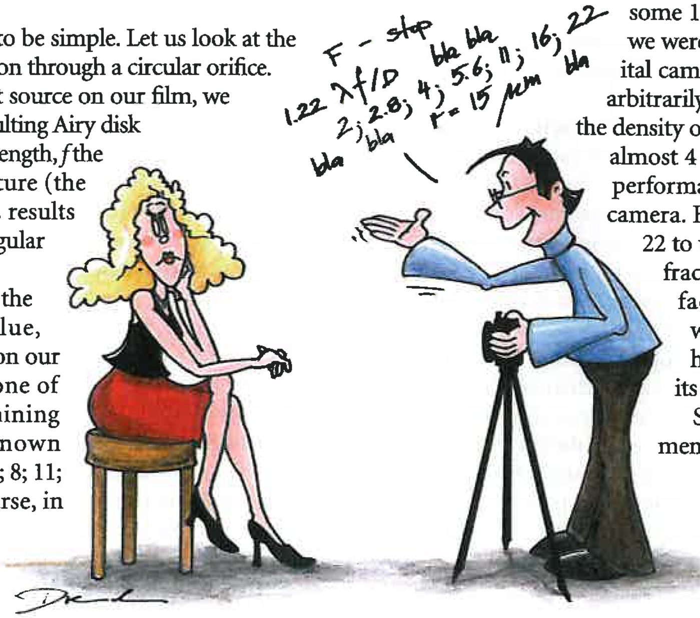
Fortunately, life turns out to be simple. Let us look at the textbook formula for diffraction through a circular orifice. When trying to image a point source on our film, we find that the radius of the resulting Airy disk is $1{,}22\lambda(f/D)$, with λ the wavelength, f the focal length and D the aperture (the funny numerical factor 1,22 results from integration over rectangular strips).

The nice thing now is that the ratio f/D is the 'F-stop' value, which we recall having used on our non-automatic camera as one of the two parameters determining the exposure. The well-known series of values is 2; 2.8; 4; 5.6; 8; 11; 16; 22, spaced by $\sqrt{2}$, of course, in order to have double exposure between consecutive values.

Now, precisely *how* seriously are we limited by diffraction? Let us take a worst-case scenario, and assume that there is plenty of light such that the F-stop 22 is chosen. The formula for the Airy disk radius yields $r = 15\ \mu m$ for the middle of the visible spectrum. In other words: we get a 30 μm diameter spot on the film, rather than a point. If we are using 35 mm film, we may want to enlarge the 24 by 36 mm frame by a factor of 10 in order to have a nice size picture. This means that the diffraction spots become 0,3 mm in diameter, and are no longer negligibly small. The conclusion is that, if we use high-quality optics in our camera, it may be wise to open up the lens much further and use smaller F-stop values.

Now let us compare this to our digital camera: Is it the number of pixels that poses the limit to the resolution, or is it still diffraction? Using the above worst-case scenario with an Airy disk radius of $r = 15\ \mu m$, and assuming the Rayleigh criterion for just-resolvable diffraction patterns (i.e., a spacing by r is adequate to distinguish two adjacent ones from one another), we find that, on a 24 by 36 mm frame, we can store some 1600 x 2400 just-resolvable spots. If we were to image that pattern on our digital camera, and if we assume – somewhat arbitrarily – that the pixel density must equal the density of the just-resolvable spots, we need almost 4 Megapixels. This is just about the performance of a modern standard digital camera. However, if we move from the F = 22 to the other extreme of F = 2, the diffraction limited spot size shrinks by a factor of 10. If the digital camera wants to take advantage of this higher resolution, it has to increase its pixel number by a factor of 100.

So there is still room for improvement in the digital-camera business. ■



◄ Why you shouldn't ask a physicist to take your picture ... (cartoon by W. Drenckhan)

Ireland beats Scotland by 0.3 %

Wiebke Drenckhan
Physics Department, Trinity College • Dublin, Ireland

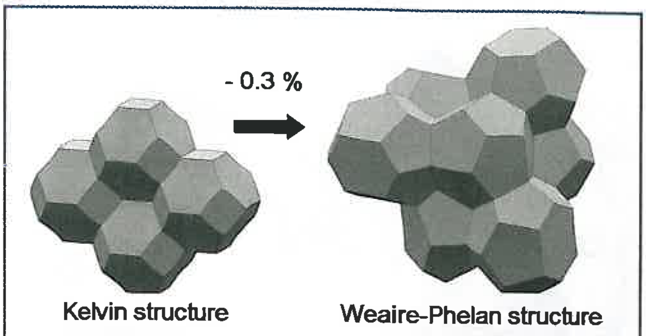
The Royal Irish Academy's highest research award, the Cunningham Medal, was recently presented to Denis Weaire, Erasmus Smith Professor and head of the Physics Department in Trinity College Dublin. This highly prestigious medal has been awarded since 1796 for outstanding contribution to scholarship. Amongst its recipients have been some of Ireland's finest scientists and scholars, including Sir William Rowan Hamilton, Frank Mitchell and Sir William Wilde, polymath and father of Oscar Wilde.

The achievements recognised with the award included Weaire's contribution to a historical debate on a deceptively simple question: How can we divide space into equal volumes so that the surface area is minimal?

The previous best was established in a conjecture from no less than the great Scotsman Lord Kelvin 1887, who had posed this question as part of his lifelong quest for a material structure of the ether of space. He suggested a structure of identical 14-sided cells, called a tetrakaidecahedra (Fig. 1). The theoretical question continued to pose a challenge to the mathematically minded long after the ether had disappeared from scientific debate. The conjecture remained unbeaten for more than 100 years until Weaire and his PhD student Robert Phelan decided to tackle it. The fruitful combination of Weaire's background in solid state physics and Phelan's skills in computer programming quickly led to the discovery of the "Weaire-Phelan structure"; a structure which is composed of two different types of equal-volume cells (see Fig. 1) and beats Kelvin's by 0.3 %. This discovery caused quite a stir among mathematicians and foam physicists. Nobody has yet come up with a better variation despite the availability of ever increasing computer power. The chances for seeing an analytical proof reasonably soon are slim. The much simpler two-dimensional analogue of this problem could only be proven in 2000 by Hales. Here the best packing is achieved by the honeycomb structure, as has long been supposed, but not with the mathematicians' certification of certainty.

To Weaire's and Phelan's delight, their structure recently transcended its status as a somewhat abstruse scientific problem when the Chinese authorities chose to make use of its artistic appeal in the design of the National Swimming Centre for the Olympic Games 2008 in Beijing (Fig. 2). This €86m award-winning "Water Cube" will be made of 4500 gigantic Weaire-Phelan bubbles, enclosed in a plastic skin. The design is not only pleasing to the visitor's eye, but also creates a greenhouse-effect to heat the building. A convenient and well-considered side-effect: the mechanical flexibility of the three-connected structure makes the building well suited to the seismic exposure of the area.

Weaire and Phelan's aesthetic design has recently been realised on a much smaller scale. Their conceptual design for a concert building, also based on their famous structure, now adorns the campus of Trinity College Dublin in the form of a large sculpture (Fig. 3). This piece of art, in particular its mirror-faces, can be taken to symbolise art and science as two faces of human culture that reflect each other in many ways. This attitude is woven like a



▲ Fig. 1: The Weare-Phelan structure (right) consists of two different types of equal-volume cells (1 Tetrakaidecahedron and 3 Dodecahedra per unit cell). It decreases the total interface area by 0.3 % in comparison to the structure conjectured by Lord Kelvin in 1887 (left).

▲ Fig. 2: The "WATER CUBE", in the foreground, in front of the main stadium. The award-winning design of the National Swimming Centre for the Olympic Games in 2008 in Beijing is based on the Weaire-Phelan structure. It was developed by consulting engineers Arup and partners, PTW Architects, the China State Construction and Engineering Corporation and the Shenzhen Design Institute, who provided the image.

▲ Fig. 3: Unveiling of the sculpture "Throwing Shapes", which presents a piece of the Weaire-Phelan structure, in Trinity College Dublin. From left to right: D. Grouse, D. Weaire, W. Drenckhan, M. Henry, R. Phelan, and J. Hegarty. The sculpture was built by D. Grouse and designed by W. Drenckhan and D. Weaire.

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▲ Fig. 4: Discovery of the Weaire-Phelan structure (the true story)

thread through Weaire's life, finding expression in activities aimed at strengthening the bridge between science and society, and was yet another motivation for presenting him with the Cunningham Medal.

The celebrations are taking place at the right time. This year, the Year of Physics, demonstrates our combined efforts to raise the awareness, acceptance and interest of science throughout society. It is time, however, to realise that this responsibility rests very much on every scientist's shoulders – and not only during 2005. ■

Sergio Fubini

Daniele Amati and Gabriele Veneziano, CERN.

Sergio Fubini passed away on 8 January, aged 76, after a prolonged illness.

Fubini was an outstanding theorist, whose deep insight led to many applications of theoretical models to more phenomenological issues. In the early 1960s, he and his co-workers gave a field-theoretical dynamical basis to S-matrix concepts such as Regge singularities. Then in the mid-1960s his group provided an algebraic formulation of current-algebra and superconvergence sum rules that played an important role in the birth of dual resonance models. Subsequently, at MIT, Sergio and collaborators factorized the dual S-matrix, converting it into an infinite component field theory, opening the way to what soon became string theory.

Wherever Sergio worked, his skill and enthusiasm left a strong mark on students and institutions, such as the universities of Padua and Turin in Italy, MIT and CERN. He was an active member of the CERN Directorate under John Adams and Léon Van Hove where he played an important role in the planning stage of the Large Electron Positron collider. In later years he devoted much effort to promoting a scientific "peace-bridge" in the Middle East that led to the creation of the SESAME synchrotron-radiation laboratory in Jordan. His rich personality will remain vivid in the memory of the many friends and collaborators who had the great opportunity of knowing him and of interacting with him. He will be greatly missed. ■

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2005 Dannie Heineman Prizes

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It is noteworthy, indeed it may even be unique, that the recipients of the 2005 Dannie Heineman Prizes are European physicists. It is also the first time that the Astrophysics Prize has been shared.

Mathematical Physics

The 2005 Dannie Heineman Prize for Mathematical Physics was awarded, by the American Institute of Physics and the American Physical Society, to Giorgio Parisi, for his "fundamental theoretical discoveries in broad areas of elementary particle physics, quantum field theory, and statistical mechanics; especially for work on spin glasses and disordered systems".

Giorgio Parisi is Professor of Theoretical Physics at the University of Rome La Sapienza. His scientific activity, of exceptional depth and breadth, has touched elementary particles, phase transitions and statistical mechanics, quantum field theory, spin glasses and disordered systems, neural networks, theoretical immunology, the construction of high-performance parallel computers.

Particle physics has been deeply influenced by the works of Parisi. His 1976 work with G.Altarelli, with its equations controlling the evolution of the parton (quark and gluon) densities as functions of the momentum, is one of the cornerstones of Quantum Chromodynamics, the theory of strong interactions, and a crucial theoretical tool for the physics of high-energy colliders such as the Tevatron at Fermilab and the LHC at CERN. His 1977-9 works with N.Cabibbo, L.Maiani and R.Petronzio exploited renormalization group techniques to establish correlations among the number of fermion families, the masses of heavy quarks and leptons, the mass of the still undiscovered Higgs particle, and the Planck scale of gravitational interactions (or, more generally, the scale of any new physics beyond the Standard Model of strong and electroweak interactions).

Pr. Giorgio Parisi

The contribution for which Parisi deserved a special mention in the motivation of the Prize is his 1979 exact solution of the infinite-range spin glass model. A spin glass is a disordered material exhibiting high magnetic frustration. Frustration refers to the fact that the different interactions in the system are in competition, and it is impossible to optimize all of them at the same time. Parisi's solution enjoys a number of spectacular properties: among others, the existence of an infinite number of ground states that are not related by an explicit symmetry of the Hamiltonian of a single system, the existence of a phase transition in the presence of a magnetic field, and the peculiar features of very slow dynamics, which implies dramatic effects such as "aging" and "memory". In his later 1983 work, Parisi found the deep physical meaning of the solution, and this led soon after to the introduction (with M.Mezard, N.Sourlas, G.Toulouse and M.A.Virasoro) of the mathematical concept of ultrametricity into the physics of disordered systems. In an ultrametric space, the standard triangular inequality for distances, $d(A,C) \leq d(A,B) + d(B,C)$, is replaced by the stronger inequality $d(A,C) \leq Max\,[d(A,B), d(B,C)]$. The states of Parisi's solution turn out to be organized in a hierarchical tree, and because of that distances among them are ultrametric. Beyond their applicability to the concrete case of spin glasses, these discoveries in the field of disordered systems opened the door to a vast area of applications, for example optimization problems such as the one of the "traveling salesman" (find the shortest route for visiting N points), neural network theories, heteropolymers folding.

Parisi's contributions to quantum field theory include the characterization of planar diagrams in O(N)-invariant theories, with implications for string theory in low dimensions, and stochastic quantization. Those to statistical physics include the study of various non-equilibrium problems, with the formulation in 1986 (with M.Kardar and Y.C.Zhang) of a stochastic differential equation for growth models for random aggregation; also, the development of new methods for the computation of critical exponents in the theory of phase transitions, for example those based on conformal invariance or on expansions of the beta function at fixed dimension.

Parisi was also one of the initiators, and for some time the responsible, of the APE (Array Processor Expansible) project of the Italian Institute for Nuclear Physics (INFN), the construction (hardware and software) of a high-performance parallel computer. The project, initially motivated by the study of Quantum Chromodynamics with the techniques of lattice quantum field theory, has now reached its third phase, and the APE machines are used for a variety of numerical simulations in a wide spectrum of fields, ranging from biological systems to turbulent dynamics. ■

Astrophysics

The Dannie Heineman Prize for Astrophysics has been awarded jointly to Professor George Efstathiou of the Institute of Astronomy, University of Cambridge and to Professor Simon White of the Max Planck Institute for Astrophysics in Munich. The astrophysics prize is awarded by the AIP and the American Astronomical Society (AAS) and will be presented to Dr. Efstathiou and Dr. White at a future AAS meeting.

The citations read as follows: The Dannie Heineman Prize for Astrophysics for 2005 is "awarded jointly to George Efstathiou and Simon White, in recognition of their pioneering research, both together and separately, into the evolution of structure in the Universe from the earliest times to the present epoch, as examples of outstanding work in the field of astrophysics."

Pr. George Efstathiou, Pr. Simon White

Efstathiou, a British citizen, is a graduate of Oxford and Durham University (PhD, 1979). Since 1980 he has worked at either Oxford or Cambridge Universities. White was born in the UK and graduated from Cambridge (PhD, 1977). Since then he has held positions in the UK, US, Israel, France, and China.

Since the discovery of the cosmic microwave background (CMB) by Penzias and Wilson observational tests of cosmological models have become increasingly sophisticated. The CMB retains the image of density fluctuations at the time when photons and matter decoupled, some 300,000 years after the Big Bang itself. Analysis of this image field can reveal the spectrum of acoustic waves propagating at that time and hence lead to detailed determination of the physical properties of the universe.

The work of Efstathiou and White has led the development of analytical approaches to extracting cosmological parameters from datasets produced by the COBE and WMAP satellites as well as a number of important balloon observatories. This process has been crucial in developing the scientific case for the ESA Planck satellite which will make the definitive measurements of these parameters and both recipients have played major roles in guiding the development of both the scientific data analysis and the scientific interpretation of the data from this mission when it is in orbit in 2007.

Radiochemistry Society International Scolarships

The Radiochemistry Society is providing $7,000 to $10,000 Fellowships to graduate students (Graduate Student Fellowships); $1,000 to $2,500 for entering university seniors (Undergraduate Scholarship). These fellowships & scholarships are open to all full-time students world wide. The number of scholarships given will depend on the total funding levels.

Selection will be based on technical merit and will be judged by Senior Technical Scientists. Individual and institutional names will be separated prior to judging to minimize bias.

Finalists will be selected and then asked to submit academic records under separate requests. Announcement of Scholarship winners will be in July of each year. For more details, see: www.radiochemistry.org/scholarship/index.shtml ■

Euroscience Open Forum 2006

The 2nd Euroscience Open Forum (ESOF) will take place July 15th-19th 2006 in Munich, Germany. The organisers of ESOF2006 now welcome contributions to the Forum's programme from scientists, journalists and experts from politics, industry and research. The call for proposals is open from March 15th until June 15th 2005. Proposals for scientific sessions and outreach activities can be submitted online at www.esof2006.org. To stimulate inspiring submissions, 18 broad themes have been selected. These themes highlight current developments in research and science policy and set the framework for an outstanding conference.

ESOF is a pan-European scientific meeting staged to provide an interdisciplinary forum for open dialogue, debate and discussion as well as showcase European achievements across the scientific spectrum. Through ESOF, researchers and scientists, as well as journalists and the general public are provided with an adequate platform for exchanging views and discussing the challenges and consequences of scientific developments around the world.

ESOF was successfully launched in Stockholm, Sweden in 2004. It attracted 1800 visitors from 67 countries. The founder of ESOF is the Organisation Euroscience, a grass-roots scientific organisation itself founded in 1997 with now over 2,000 members in 40 countries.

In order to promote dialogue between science and society, ESOF2006 will be jointly held with the Wissenschaftssommer (German national science week) in Munich. The Wissenschaftssommer is organised annually by Wissenschaft im Dialog, an initiative of the Stifterverband für die Deutsche Wissenschaft and other German science-funding organisations.

In its work ESOF2006 is supported by a number of committees. The Steering Committee is chaired by Prof. Dr. Wolfgang Heckl, General Director of the Deutsches Museum in Munich. Host of the conference is Wissenschaft im Dialog gGmbH. ESOF2006 is to date generously supported by two initiating partners, the Robert Bosch Stiftung and the Stifterverband für die Deutsche Wissenschaft. ■

FOM initiates Center for Nanophotonics in Amsterdam

The Foundation for Fundamental Research on Matter (FOM) has established a Center for Nanophotonics at the FOM Institute AMOLF in Amsterdam, The Netherlands. In this Center, over 40 researchers will collaborate in a large-scale research program on nanophotonics. One of the Center's research groups is stationed at Philips Research in Eindhoven to enable efficient knowledge transfer.

Nanophotonics is the research field that studies the generation, manipulation, storage, and amplification of light at length scales that are typically smaller than the wavelength of light. Within the nanosciences, nanophotonics is a research field that is still in its infancy. Yet, it is expected that within 10 years nanophotonic technology can have the same impact on our society as micro-electronics has today. By establishing the center, The Netherlands can play a leading international role in establishing the nanophotonics research field.

Applications of nanophotonics include communications technology, lasers, solid-state lighting, data storage, lithography, (bio-)sensors, optical computers, solar cells, light-activated medical therapies, displays, smart materials. Because of the importance of these applications there is large interest from industry in fundamental research and innovations in the area of nanophotonics.

The Center's scientific group leaders are: Prof Albert Polman (head), Dr Jaime Gómez Rivas, Prof Kobus Kuipers, Prof Ad Lagendijk, Dr Jan Verhoeven, and Prof Willem Vos.

The Center's official opening will take place on 7 April, 2005. ■

INTAS

On 4 April 2005, INTAS, the International Association for the promotion of cooperation with scientists from the New Independent States (NIS) of the former Soviet Union, launched the first stage of its Open Call for Research Projects Proposals 2005-2006.

With an indicative budget of ?12 million, the INTAS Open Call 2005-2006 encompasses basic and applied research with no thematic or geographical restrictions, but excluding market-oriented technology development. Unlike previous open Calls, it will not be open for network proposals.

This open call will be implemented in a two-stage submission procedure according to which participants will first submit a short outline of the proposal (called "a pre-proposal"), and only applications passing the evaluation in the first stage will be invited to submit a full proposal. Whilst the deadline of the first stage is 14 June 2005, 09H00 Brussels time, the launch date of the second stage is 5 September 2005, 9h00 Brussels time, with a deadline on 10 January 2006, 9h00 Brussels time.

This two-stage submission procedure will also be implemented in some of the other thematic and collaborative Calls 2005 for research project proposals, which will be launched on 03 May 2005:

1. INTAS Thematic Call 2005 on Genomics and Proteomics applied to Human Health.
2. INTAS Thematic Call 2005 on Hydrogen Technology and Biomass Conversion Technology for Energy Generation.
3. INTAS Collaborative Call 2005 with CERN in the field of LHC Experiments Preparation and Data Analysis Security.
4. INTAS Collaborative Call 2005 with Moldova.

On the same date, INTAS will launch a call for applications for Innovation Grants. Early June 2005 a series of Calls for applications for Young Scientist Fellowships (YSF) will be launched, including Calls in cooperation with Moldova, Georgia, CERN and DESY. Finally, INTAS plans to launch in autumn 2005 one more Thematic Call on Social and Human Sciences, whose exact title will be specified later.

The corresponding call announcements containing the detailed schedule, scope and deadlines will be published at the launching date together with information packages containing the general rules for submission of proposals.

In addition to these Calls, information about INTAS Summer School support and Conference Grants will soon be published on the INTAS web site.

The Information Packages and a Technical Guide on the electronic submission for each of the actions can be obtained on www.intas.be, Section "Funding Opportunities" as soon as the Calls are open. For further questions on the INTAS Calls 2005, please send an e-mail to infopack@intas.be

For general information about INTAS, please contact the Public Relations Team at info@intas.be or by fax: +32-2-549 01 56, or check our web site at www.intas.be ■

Biggest ever Physics Congress in Australia kicks off World Year of Physics

Hans-A Bachor

During February more than 900 physicists gathered in Canberra, Australia for the Congress of the Australian Institute of Physics with the theme: "Physics for the Nation". They enjoyed a very widespread program, covering many aspects of physics from atmospheric science and global climate change to quantum information and the detection of gravitational waves. A program of plenary speakers provided clear and entertaining introductions while the parallel sessions allowed detailed discussions.

Many students attended and an overwhelming optimistic view of the future of physics emerged. The attendees are keen to continue their research and to educate the public about the need to make public decisions based on scientific consensus.

The Congress had a lively outreach program that attracted school children from across the state – a great opening for the World Year of Physics' celebrations in Australia. The program featured extraordinary performances from speakers such as Karsten Danzmann, on Listening to the Universe and Albert Einstein listening intently.

▲ Fig. 1: The EPS President, Martin Huber, talking with Professor John Sandeman, ANU.

▲ Fig. 2: Professor Karsten Danzmann presenting his talk with an Einstein Impersonator listening intently.

We enjoyed the company of many representatives of international associates, including Martin Huber representing the European Physical Society. ■

EPS Platform on Physics Education Issues

The Executive Committee met in Vilnius, hosted by Z. Rudzikas and the Lithuanian Academy of Science for its 3rd Journée de reflection. The theme of this year's JdR was decided by the Executive Committee to prepare the action plan of O. Poulsen, the EPS President-elect, who will take up his functions following this year's Council meeting in Bern.

Presentations began with an introduction by O. Poulsen. He stressed the need for science education that will allow citizens to understand the issues and technology that will shape their lives. C.Madsen, representing the EiroForum, explained what activities the 7 large European research organisation are doing in the fields of outreach and education, highlighting the Nucleus project. This was followed by an overview by E. Johansen, chairman of the EPS Education Division, of the challenges faced by the working physicist in being involved in education and outreach, especially a project in Stockholm that makes scientists and equipment available to school classrooms. H. Busch presented the ROSE project which is studying the attitudes of adolescents all over the world with regards to science and technology. Its preliminary conclusions show a divergence in belief that science and technology are important (relatively positive), with the lack of interest in following careers in this field. Next up was J. Holbech who introduced Higher Order thinking (HOT) and how working on analytical and problem - solving skills helps students not only understand physics, but other educational topics. J. Ogborn presented a UK initiative "Advancing Physics", which has introduced into some schools in the UK new teaching methods which have renewed interest and performance in physics teaching and studies. L. Vingelienne, ended the JdR with a presentation of an EC funded project to exchange best practice in physics teaching.

The result of the JdR will lead to an EPS position paper, and an action plan which will allow the EPS to make contributions to the issues and problems that are faced in physics education. ■

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Foundation for Fundamental Research on Matter

The Foundation for Fundamental Research on Matter (FOM) promotes physics research of international standard/calibre in the Netherlands. It conducts scientific research and plays a stimulating and co-ordinating role on a national level in (para)academic physics research. FOM employs about 1100 people, consisting primary of scientists (including PhD students) and technicians. These operate in four research institutes and approximately 200 research groups at general and technical universities. FOM is chiefly financed by the NWO (Netherlands Organisation for Scientific Research) Governing Board and NWO Physics and can be considered as the Physics Division of NWO. In addition to the government funds of NWO, FOM acquires financial means from the European Union and through collaboration with the industry and universities. For additional information see http://www.fom.nl

AMOLF is a research institute of the Dutch Foundation for Fundamental Research on Matter (FOM). Its laboratory in Amsterdam houses approximately 100 scientists, 50 technical engineers, and 25 supporting staff with an average age of 36 years. The research program focuses on the physics of biological processes, on nanostructured opto-electronic materials, and on ultrafast laser spectroscopy. AMOLF's mission includes the training of scientists and technical engineers for advanced research, as well as the transfer of knowledge to industry and society. The construction of a new building in the next few years demonstrates the commitment of various parties in the Dutch science policy scene to ensure a healthy future for the institute. The FOM organization invites applications for the position of

Director of the FOM Institute AMOLF

FOM seeks candidates trained in (experimental) physics or adjacent fields, with an excellent scientific track record and with a vision for innovative research. The director of the institute will set the course for the institute as a whole, but will also have the opportunity to conduct his/her own research program. A joint appointment as professor at one of the Dutch universities will be made available. Because of the significant general management responsibilities, candidates are expected to know or learn Dutch.

Information about the position and the strategic direction of AMOLF can be obtained from Dr. Hans Chang, Director of FOM, telephone +31 (0) 30 600 12 26, and from professor Daan Frenkel, member of the management team at AMOLF, telephone +31 (0) 20 608 12 34. For contact information, see the web sites www.fom.nl and www.amolf.nl

The function is remunerated at the level of a full professorship in The Netherlands. The appointment as director is for 5 years and will normally be renewed for another 5 years. The employment contract with FOM is permanent.

Applications for this position should be sent before 27 May 2005 to the Director of FOM, P.O. Box 3021, 3502 GA Utrecht, The Netherlands. Please include a curriculum vitae, a list of most important publications, a statement of research interests, and a description of management

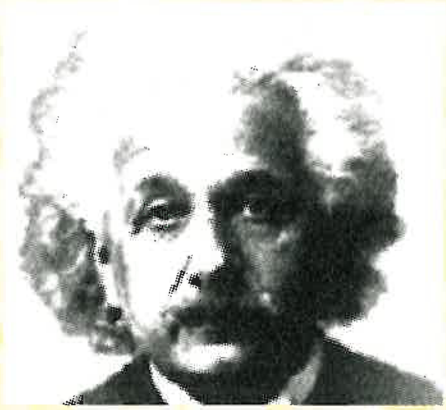
The European School on Nanosciences and Nanotechnologies will be held on August 21st - September 9th 2005 in Grenoble, France (www.esonn.inpg.fr)

The three weeks programme includes lectures and practical work in clean room facilities and research laboratories and will cover the elaboration, functioning and characterisation of nano-objects.

Two sessions (physics and biology) will be run in parallel.

Applicants are expected to be graduate students, postdoctoral and scientists from academic or industrial laboratories.

13th General Meeting of the European Physical Society - EPS-13



The 13th General Conference of the European Physical Society, "Beyond Einstein – Physics for the 21st Century" will be a scientific highlight of the World Year of Physics, also declared International Year of Physics by the United Nations. This Conference offers a unique opportunity to present your research in fields that were opened by Albert Einstein through his three most famous papers, which he published in the annus mirabilis 1905. EPS13 is being organised jointly by the EPS Divisions and Groups, and will comprise three parallel scientific conferences, namely

1. Photons, Lasers and Quantum Statistics
2. Relativity, Matter and Cosmology (with ESA, ESO, CERN)
3. Brownian Motion, Complex Systems and Physics in Biology

Each one of these conferences will consist of three to four topical symposia that are described in detail below. Plenary, invited and contributed talks are planned. EPS13 is specifically designed to attract young researchers, thus ample room is given for poster sessions as well as contributed oral talks. 800 to 1000 participants can be accommodated.

An Open Day on Physics and Society, co-organised with the Swiss Academy of Sciences and the Swiss Physical Society, will address a wide public under the title "Einstein Today".

EPS13 is one of the scientific and educational events organised by the Forum Einstein 2005 Bern: EPS13 participants are invited to take part in other events organised by the Forum , such as the official Einstein celebration to be opened by the President of the Swiss Confederation.

Bern with its beautiful city centre will welcome you with a rich programme of cultural and other events. Before and after EPS13 several excursions to the picturesque surroundings of Bern and into the Alps are being offered.

Participating organisations

Be RN

CERN

EPS

World Year of PHYSICS 2005

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