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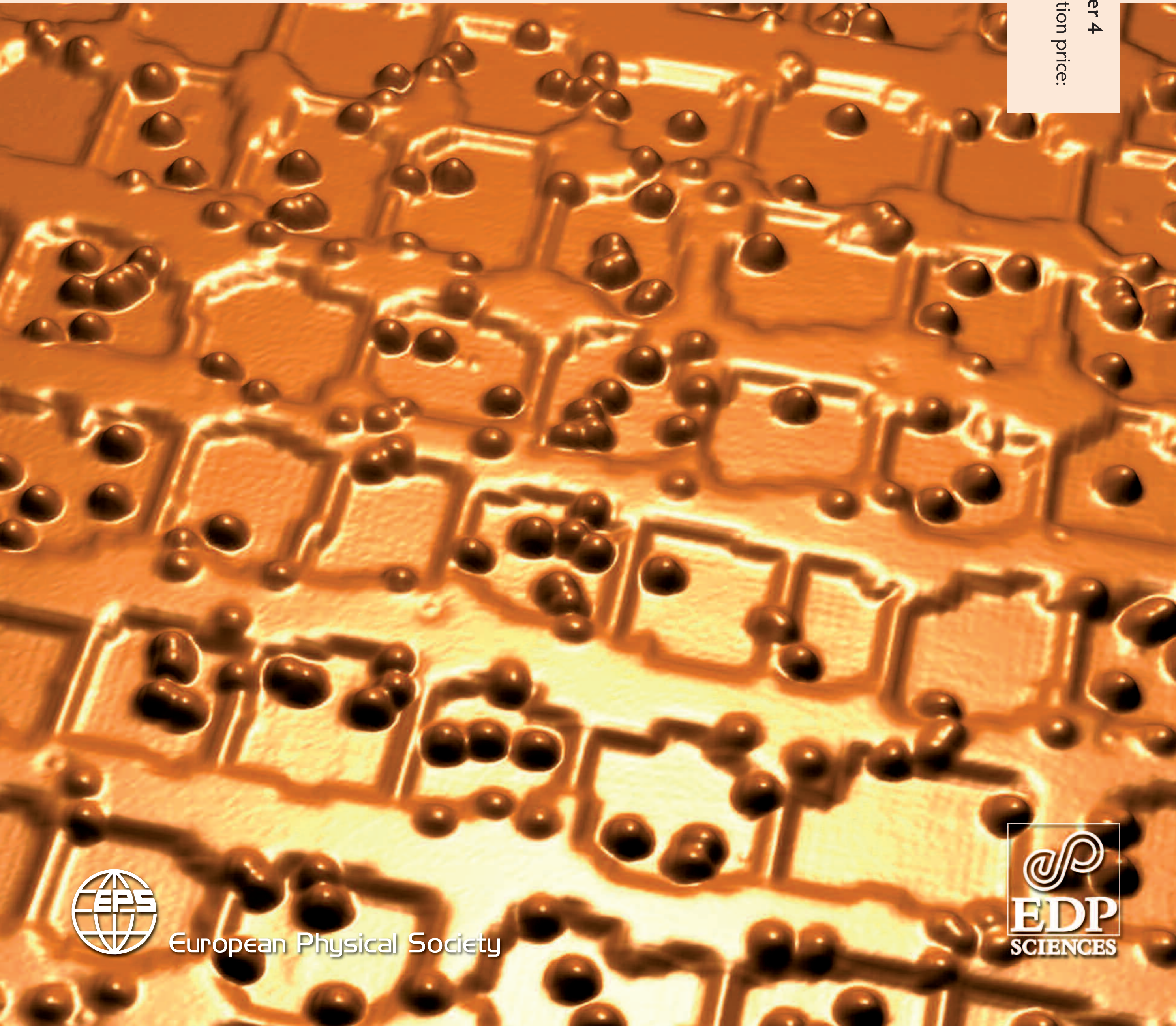
Physics in space (part 2)

40 years of EPS

Can data be stored in a single magnetic atom?

Hearing glasses

Feeling hot, feeling cold



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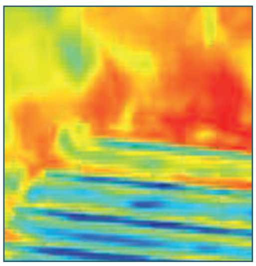
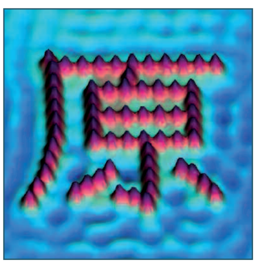
2008 • Volume 39 • number 4

cover picture: Copper nitride islands on a copper substrate seen by scanning tunneling microscopy. See article p. 31



▲ PAGE 23
Bubbles, drops, films: transferring heat in space



▲ PAGE 31
Can data be stored in a single magnetic atom ?

▲ PAGE 39
Museum review: Deutsches Museum

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UNIVERSITIES, PHYSICS AND HIGHER EDUCATION

»» EDITORIAL

The research scene is changing rapidly these years. We all experience these changes whether we are seniors in science leadership, active scientists or young researchers fighting to gain a foothold. These changes are best characterized by the word corporatization.

Today science is viewed as a catalyst for economic growth, science funding is regarded as a strategic commodity and researchers as soldiers of war. In this development we see signs of a worrying nature, mostly in the interplay between higher education (HE), research and research funding and university employment.

In the US, aspects of this discussion have recently surfaced by the observation that young researchers face difficulty in attracting independent funding. Funding that increasingly is focused onto the strategic sphere following Matthew 13:12 that, *"for to those who have, more will be given, and they will have an abundance; but from those who have nothing, even what they have will be taken away"*.

This principle holds true both on the level of individual researchers, research groups and on the institutional level. This historical trend, from *unfettered serendipity towards strategy and societal relevance*, leave universities (and physics) with difficult choices on robust strategies in years to come.

Universities are responsible for development of talent through advanced education, PhD. training and post-doctoral employment. Successful hiring of new staff depends on this pool of new talent. However, the ability of universities to hire the best also depends on the status of the individual university as measured by status and ratings. X-factors (X=H) play more and more important roles in the corporatization and growth of modern universities. Ratings are today adapted in most countries under acronyms like "elite initiatives"; Matthew is alive and functioning.

This development has taken place during a period of time, where recruitment to modern science, particularly the exact sciences, has become increasingly difficult, while enrollment in non-science HE-programs generally has soared. It is my claim, that we must take a closer look at the science HE-system and its relation to the modern *research industry*. I further claim that the corporatization of science implies less readiness to take up risky research and that a lack of balance between *unfettered serendipity* and *strategy reduces* our ability to develop a strong science basis, in particular with a mind on higher education and the ability for young students to see themselves as part of *e.g.* physics.

There are two opposite forces at play in this development. Firstly, the owners of public universities expect a rate of return on their investments. Universities, on the other hand, have traditionally valued their independence. These two opposing trends are at loggerhead in today's development of modern universities. It is in this process that focus has been put on research performance more than on nurturing a new generation of creative and highly trained young scientists. Research may be "industrialized", but higher education certainly can not.

This is where the physics community could take action. Only those fields of science that can "win" the best of each generation, will stand a chance to develop themselves. This means more focus on physics curricula, advanced didactics and, most importantly, an attitude also making room in physics for groups of students not aspiring to become university physicists themselves. As for young physicists, opportunities must be established for them to prove themselves early in their career. For women physicists there exists a particular need for career planning in respect of family concerns.

Corporatization in this sense implies finding a proper balance between the human factors so central to higher education and the innovation potential inherent to advanced research. ■

Ove Poulsen,
Past-president of the EPS (2005-2007)

REMARKS ABOUT

ENERGY AND ENERGY RESEARCH

»» 40 YEARS OF EPS

Alex Bradshaw,
Scientific Director of the Max Planck Institute for Plasma Physics, Germany

After-Dinner Lecture given on the occasion of the 40th anniversary of the European Physical Society on 28th March 2008 in Mulhouse.

Ladies and Gentlemen,

A few months ago the President of the European Physical Society, Fritz Wagner, asked me to address the assembled participants of this anniversary event and their guests, because he felt that it required an Anglo-Saxon to make a witty speech during dinner! I have chosen, however, to say something more serious. This is not the result of my sense of humour having been blunted by living for many years in Germany (as Fritz immediately suggested!). No, I felt that you – my captive audience for the next 30 minutes – deserve something more intellectually challenging than a string of anecdotes or funny stories about physics and its European practitioners, or indeed about Europeans and their cultural differences, something for which we should actually be thankful!

◀ Alex Bradshaw

I have therefore decided to discuss the concept of sustainable development and – in this context – to make some remarks about energy and energy research. The EPS has concerned itself particularly with this topic during the presidency of Fritz Wagner. Some of the things that I will say you have no doubt heard before. A few things may be new to you and some of them may be controversial.

I would like to begin by noting that the last four decades of the 20th century were characterised by an increasing concern about the degradation of the environment and the depletion of natural resources. Perhaps it was the book by Rachel Carson *"Silent spring"* in 1962 which first drew the attention of the general public to the problems of mankind's influence on its environment, in particular to pollution in the developed world and to the potential, now all too apparent, loss of bio-diversity. Moreover, the years that followed were characterised by a series of man-made environmental disasters, which in the perception of the public probably began in Bhopal in India, but culminated in Chernobyl. The report of the Club of Rome, *"Limits of Growth"* written by Dennis Meadows in 1970 pointed out that prosperity was dependent on sufficient supplies of raw materials, and in particular on cheap sources of energy in the form of fossil fuels and that these were finite. The assumptions made by Meadows in his computer models were not all correct and the predictions, as it turns out, were wholly incorrect. Nevertheless, the book forced scientists and economists to think about the use, or rather flagrant misuse, of the resources of the planet.

The onset of mankind's detrimental influence on the environment is generally thought to be the industrial revolution in Europe. But there are earlier examples. In his book *"World Fire"* the historian Stephen J. Pyne describes how the Australian aborigines radically changed the landscape of the continent by the use of fire when they settled there 40 thousand years ago. Laurion, where the Athenians mined their silver, was already regarded in the 4th century BC as an unhealthy area. Socrates remarks, in a conversation reported by Xenophon, that a young politician was not expected to pay a visit there. The condition of the slaves who actually worked in the mines was apparently not a matter with which the Athenians necessarily concerned themselves! In more modern times we can cite the destruction of hundreds of thousands of square kilometres of forest land between the 13th and 18th centuries in Europe in order to create more agricultural land to feed the growing population of the towns.

Thirteen years after the Club of Rome report, the United Nations set up the World Commission on Environment and Development under the Chairmanship of the former Norwegian Prime Minister Gro Harlem Brundlandt. Its report *"Our common future"* in 1987 made the now accepted definition of sustainable development as development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs." The pillars on which it rests are environmental responsibility, economic sustainability and social development. Some sources would add *"using sound science in a responsible way"* and *"promoting good governance"*. However, as the UK government has recently pointed out in one of its publications, *"globally we are not even meeting the needs of the present let alone considering the needs of future generations. Unless we start to make real progress toward reconciling these contradictions we face a future that is less certain and less secure. We need to make a decisive move toward more sustainable* *development. Not just because it is the right thing to do, but also because it is in our own long-term best interests."*

Whereas most of us are aware of what sustainable development means, it is true to say that in the last decade the concept has not played such an important role in the media and in political debate, as it did when it was first defined in the 1980's. Although the questions of energy supply and climate change now occupy the political stage, the underlying philosophy and the various other aspects of sustainable development are no longer so prominent. Who remembers the World Summit on Sustainable Development in Johannesburg in 2002? Who is aware, for example, that the first EU sustainable development strategy was launched at the Gothenburg summit in 2001 and that the European Council in accepting a progress report from the Commission on the implementation of the strategy in December 2007 reiterated, *"sustainable development is a fundamental objective of the European Union"*? Does the British public still know that the Government launched its sustainable develop¬ment strategy in 2005 under the slogan "Securing the future"? Is the German populace waiting with baited breath for the progress report on the national sustainability strategy this autumn? To confuse matters more, the media quite often use the word "sustainable", but not in the sense I have defined, but rather to mean "long-term" or "lasting".

Who is concerned about the consumption of precious natural resources, anyway? Assuming Europeans were to know that in 2006 only 11% of the platinum contained in automotive catalytic converters was actually recovered, would they actually worry about it?

A short aside: The word "sustainability" was not part of the English language before 1987. A German translation, namely,"Nachhaltigkeit" was, however, readily found: it describes the principle on which forest management has been based in Central Europe for over two hundred years. Indeed, the concept, and the word "nachhaltig", is used by Oberberghauptmann von Carlowitz in his *"Sylvicultura Oeconomica"* in the year 1713. In other words, the Germans had a word for it; the Anglo-Saxons had to invent one! (Most of this information is available in Wikipedia. However, since I used some of these ideas in a similar lecture given some years ago, it is not I who is guilty of plagiarism. Anyway, as Alfred Polgar the Austrian theatre critic once said *"Plagiarism was always the most honest way of expressing admiration"*.)

Now some more fundamental thoughts: The realisation of sustainable development depends on the availability of sufficient energy. Matter and energy are subject to laws of conservation. In natural, non-radioactive processes the total number of atoms of each element remains constant. An element can of course be degraded in that it may form a less valuable chemical compound, for example an oxide from a pure metal, but the process is reversible. We can recover the pure metal. Energy, on the other hand, regardless of its origin – solar, fossil fuel, a nuclear process - is irreversibly degraded by its use. The total quantity of energy remains, but the result of any conversion process (whether it is for electricity generation, heating or transport) is that high-grade energy is changed into low-grade heat. The petrol in a car, for example, produces heat and mechanical energy that drives it. The motion of the car is only possible against the various forces of friction. The friction of the tyres on the road and of the car in the air leads to a heating of the environment.

The so-called degradation of the elements, on the other hand, can be reversed, but *only if sufficient energy is available*. Oxidised or corroded metals can be reconstituted, water can be purified or desalinated, consumer products can be re-cycled, but the crucial factor in closing such material cycles is the input of energy. Even achieving so-called "soft" sustainable development requires considerably more energy than is realised and certainly more than is normally allowed for in predictions of future world energy consumption, at least on the basis of present assumptions concerning population and economic growth.

In a further aside, this time on the Second Law, which I have not yet mentioned by name: One remembers the statement by the novelist and physicist Sir Charles Snow in a much-quoted lecture in 1957 that it was just as important for the student of the humanities to appreciate the Second Law of Thermodynamics as it was for the scientist to be familiar with the ▶

works of Shakespeare. The problem was that a whole generation of non-scientists – at least in the Anglo-Saxon world – tried to follow Snow's advice and were understandably left frustrated and disappointed by their attempts to master the Second Law. When the public understanding of science movement actually took root, it was not as a result of the adage of Snow. On the contrary, the initiators were biologists who realised that there was a direct way of tackling the problem!

To return to our theme: We have a paradoxical situation: achieving sustainable development requires more energy, but our energy system itself is far removed from satisfying sustainability criteria. Over 80% of the world primary energy supply of 477 EJ (in the year 2005), or 11.4 Gtoe, is provided by fossil fuels. The percentage is actually rising. A very small proportion of the energy of the sun incident on the Earth over millions of years has been stored in the form of coal, oil and natural gas. Mankind is currently squandering these precious natural resources over a period of a few centuries and, at the same time, increasing the CO_2 concentration of the atmosphere in an alarming way. Global warming and serious climate change are known to result. Conventional oil reserves are expected to last about 50 – 70 years at the present rate of use. The "Trend lines" peak oil production forecast is 91 million barrels per day (mbd) in 2013, staying constant for several years, before declining. (In 2008 we will already reach 87 mbd). Oil shales and natural gas will be with us somewhat longer. World coal reserves are sufficiently large to supply us for two to three further centuries. The same is true for the uranium fuel of conventional fission reactors, which – although they do not produce CO_2 – are subject to critical scrutiny in many countries because of the safety issue and the sustainability problem posed by the unavoidable production of highly radiotoxic waste, a point to which I will return. Moreover, world energy demand is likely to increase drastically in the course of this century: the present world population of 6 billion could double by the year 2100. Finally, we note that emerging economies have already begun to benefit from the fruits of stronger economic growth and thereby increase their demand for energy. The thirst for energy in China, and the construction rate of new coal-fired power stations are phenomenal. *The Economist* reported recently that in the two years 2006 and 2007 China created a total extra generating capacity larger than that currently available in the whole of France!

I would submit that the answer to the problem is an apparently simple "energy agenda" which proves to be very difficult in practice to realise: In order to drastically reduce the use of fossil fuels it is necessary:

1. to promote the use of renewable energy forms (provided they fulfil sustainability criteria)
2. to achieve a more rational use of energy,
3. to improve the efficiency of energy conversion processes and
4. to explore fully all future options even if some of them do not necessarily fulfil the strict definition of sustainability.

These measures require that the fraction of GDP spent on energy research and development be drastically increased, because here we are doing very badly. And there are substantial differences between European countries. Germany spends – according to the statistics of the International Energy Agency (IEA) in Paris – 0.016% of GDP on energy R&D, whereas the energy sector share of GDP is about 10%. However, France, Finland, the US and Japan all spend more – again as a percentage of GDP. Japan actually spends four times as much! Germany, however, is known for its very high subsidies for solar energy and wind, although – as a result of a decision of the European Court in Luxemburg they are not officially regarded as subsidies and enjoy the description "feed-in tariffs". Just on a point of interest, Germany actually spends even more on subsidising its national coal industry, a sum last year of no less than 3.5 billion Euro! But energy research is bound to become more important as the situation worsens, since it offers one of the very few hopes for the future. Perhaps most important of all for us gathered here to celebrate 40 years of the European Physical Society is to reflect upon the fact that physics may soon return to the top of the research agenda! With an oil price over 80 $ per barrel and G8 summits dominated by energy and climate issues, physics, but also chemistry and engineering, which provide the bases for new technologies, should come into their own.

All four points on the agenda I have just mentioned are expensive and in themselves will cause the price of energy to rise. It will of course rise steeply anyway when supplies of fossil fuels dwindle in the second half of the century, but by then billions of tons of valuable raw materials will have been exhausted and there will probably have been irreparable damage to our environment.

Time does not permit me to discuss all the points on the agenda but I am going to look briefly at two options under the fourth point, namely, nuclear fission and nuclear fusion.

View of the diner during the lecture.

The IEA forecasts that the percentage of nuclear power in world energy supply is likely to remain constant at 5% until 2020, despite the fact that this is hardly a sustainable solution to our energy problem. The 5% means that 10,000 tons of spent nuclear fuels are produced per annum with the concomitant problem of final storage. It is therefore strange that research into partitioning and transmutation, which is the process of degradation of highly radioactive actinides into stable or short-lived isotopes, is not carried out with more decisiveness. The accelerator-driven subcritical reactor-based system MYRRHA has still not been funded. The much-discussed Generation IV, which is still on the drawing board, contains power-plant designs based not only on the high-temperature reactor but also on the fast reactor principle that uses a minimum of nuclear fuel and above all can substantially reduce the amount of radiotoxic waste. The potential problems of the fast reactor are well known, and proliferation is always cited as a major one, but they could give us some respite, enabling us to win time, so that more sustainable solutions to the energy crisis can be found. Generation IV contains enormous challenges for physicists and engineers.

Last but not least, I come to nuclear fusion. Recent advances in high-energy plasma physics show that fusion – the energy source of the sun and other stars – could provide the cornerstone of a sustainable, or almost sustainable energy system. Such power plants would be safe and environmentally friendly. In particular, one of the main problems of fission reactors, namely that of a possible uncontrollable nuclear reaction is banished; also the problem of radiotoxic waste is reduced by many orders of magnitude compared to present fission reactors. Fusion reactors would have almost limitless supplies of fuel and could be sited anywhere in the world. Fusion is, however, still in the development stage and it is not expected that commercial power plants will start operation before the middle of this century.

The fuel in a future fusion power station will be a mixture of deuterium and tritium. The reaction produces an alpha particle, a neutron and a considerable quantity of energy, which is distributed between the two particles. The aim of fusion research is to produce schemes in which the deuterium and tritium nuclei approach each other sufficiently often and with sufficient energy that the reaction takes place. At present, the most successful scheme is to contain the hot, ionised gas – the plasma – in a toroidal magnetic field cage and to heat it with microwaves. This, however, requires the input of energy. A successful fusion power plant requires that the power amplification factor, i.e. the ratio of the power produced by the fusion reaction to the power required to heat and control the plasma, lies ideally between 20 and 40. Of the reaction products, the alpha particles lose their energy to the plasma and thus serve as heating; the neutrons leave the plasma and are stopped in the so-called blanket, where they deposit their kinetic energy as heat, which in turn produces electricity via steam generation in the conventional way.

It is one of the success stories of European science that the EURATOM fusion programme has taken research in this field the farthest. The break-even point, *i.e.*, a power amplification factor of unity, was all but reached on the joint European experiment JET in Culham, UK in 1997. 16 MW of fusion power were achieved for about a second and about 4 MW for a few seconds. JET is operated not as an institutionalised international research centre, but rather jointly by the national fusion research laboratories. These also have their own programmes, but they are in turn co-ordinated and linked within the European fusion programme. As was remarked by the last external panel that evaluated the European fusion programme, there is no better example for the European Research Area.

The next step in the fusion programme is the construction of the international experiment ITER in Cadarache in the South of France which will demonstrate that a plasma can burn under energy-producing, power-plant conditions for periods of up to many minutes. A power amplification factor of at least 10 is the aim. The following step will then be the construction of a demonstration power plant, which will actually produce electricity. Unfortunately, the process of building and testing these two devices and the accompanying technology programmes are likely to take another forty years, so that fusion could only play a significant role in energy supply in the second half of this century. Nuclear fusion as an energy source is often referred to derogatorily as a "moving target": back in 1960 it was 40 years in the future, and now it is still 40 years away! The early fusion physicists were of course too optimistic in their predictions, but this particular criticism neglects the enormous progress that has been made, particularly in the last two decades, and the long waiting time for projects to be approved. Exactly 20 years elapsed between the setting up of the initial ITER planning group in Garching and the signing of the ITER agreement!

Why do I describe fusion as a sustainable, or almost sustainable energy source? Of the fusion fuels, tritium has to be bred in situ from lithium in the reactor itself, but sufficient lithium is available in the Earth's crust for tens of thousands of years and in seawater for at least a million years. There is sufficient deuterium in seawater for an even longer period. Indeed, if it were possible to improve the energy confinement of fusion reactors such that the lower cross section deuterium-deuterium reaction, instead of the deuterium-tritium reaction, could be used the available fusion fuel would last for billions of years, in any case longer than the lifetime of the sun. A truly sustainable solution!

As physicists, I feel we have the responsibility to develop the option "fusion" to a point, such that future generations – it may not be our children or even grandchildren – can make a decision based on economic, social and environmental factors relevant at the time. The Göttingen physicist Friedrich Hund was, as far as I am aware, one of the first to discuss the physical basis of the supply and use of energy in an essay entitled *Die physikalischen Rahmenbedingungen unseres* Daseins written in 1975. He noted, *"If we are not successful in getting fusion to work, then mankind will soon have to manage with the sun alone"*. ■

REPORT ON M. GAGO TALK:

"HOW EUROPE CAN BOOST RESEARCH IN PHYSICS" ››› 40YEARS OF EPS

M. Ducloy [1] and **M. Leduc** [2],
[1] Former President of the EPS (2001-2003), [2] President of the French Physical Society

Mariano Gago came to Mulhouse for the celebration of EPS 40th anniversary. He delivered an enlightening speech reflecting his analysis and vision of the European Research Area, and its impact on the development of Physics. M. Gago has been an active physicist at CERN and was one of the main negotiators of the integration of Portugal into the CERN organization. In the early 2000's, at the time of the establishment of the European Research Area, he was Minister for Science and Technology of Portugal (1995-2002). Since March 2005, he has been back in the Portuguese government as Minister for Science, Technology and Higher Education. Here is a summary of the message that he delivered in Mulhouse.

Learned societies have a pre-eminent role

Mariano Gago was a student when EPS was founded in 1968 and did not care much about it. But he became progressively more and more respectful of the international learned societies that helped to shape the European Research Area. At a national level the learned societies have long been influential regarding decisions taken by policy makers. At the European level this is a relatively new process; international organizations entered into the game at different paths, slowed down by bureaucratic trends. An example of difficulties still to be solved is given by space policy: is there a need for a European Space Agency?

The role of learned societies has been very critical for the creation of the European Research Council (ERC). In early 2000, when the idea was first discussed that science is a major component of economic progress, there was more consensus among the ministers of individual European countries than among the officers at the European Commission. They would not admit the role of fundamental research as a key ingredient and would consider that science at the European level is just for industrial competitiveness, with an exception for biology. When the 7th PCRD came under discussion, nobody supported programmes for basic science; it was crucial to reverse opinions fast, and also important to prevent biologists from going it alone. EPS was then extremely active in the formation of a "platform" of all European learned societies: physics is a powerful field which helped other disciplines to adopt a new perception. This European platform was very efficient, and accelerated the creation of ERC in December 2006.

Research budget issues at national and international levels are crucial. This particularly concerns human resources, for which the competition becomes increasingly difficult: governments cannot afford society criticism by not paying enough attention to this key point. It is striking that all countries without exception agree now that their R and D budget funding must increase, as a result of the scientists' action, even if other expenses will be reduced. M. Gago considers that the situation for science is thus rather good, with a recognized goal of 1% of GNP invested in public research funds – another 2% being expected from Industry to reach the basic figure of 3%.

▼ Mariano Gago during his talk

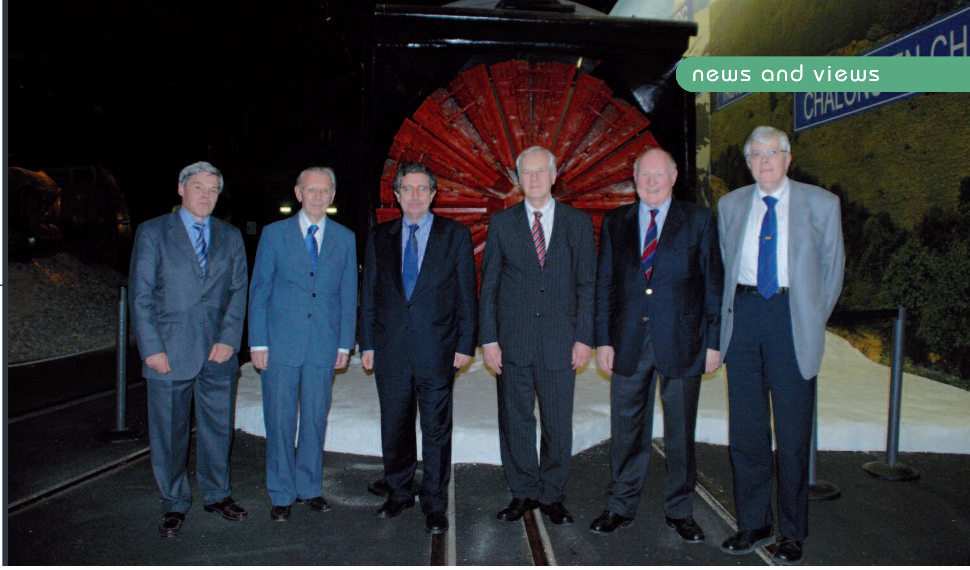
Intergovernmental organizations

Large scale infrastructures are a major element of European science policy. CERN or ESO have been for long established with the cooperation of nearly all countries and are undoubtedly a major success of European research endeavour. Are constructions of that scale desirable for the future? Should they concern all states or just a few of them? Some countries having no funds but much guilt ask for research infrastructures on their territory. There is actually a need for a realistic road map for new infrastructures in Europe. Are decisions to be taken by member states or by the EC, which could provide 50% of the budget provided that the rest is found by the states? The community appears divided on this matter.

Similar questions can be raised on the funding of postdoctoral researchers of a given nationality in a different country, which should be combined with transnational projects. One notes the recent expansion of the scientific community across frontiers. National agencies have to take this fact into account, and either open up their programmes or keep strictly on their national basis. EPS should participate in the discussions of these policy questions that will quickly rise.

Teaching physics must open up

After dominating the field of science for decades, physics is now a discipline in steady decline regarding its attraction for young students. Conversely life sciences (biology and medicine) have undergone a tremendous development and appear more appealing. The new generation of students is more conscious of the problems of the world and the biosciences appear to them as a more open discipline than physics in which they feel encapsulated. Such a difference between these two major domains is obvious when considering the number of women involved. There is a very large deficit of women in research in physics, and thus a large opportunity for



Mariano Gago with EPS past presidents, from left to right : Martial Ducloy, Herwig Schopper, Mariano Gago, Fritz Wagner, Martin C.E. Huber and Ove Poulsen ▶

the growth of activity in the domain, following the example of the biosciences.

In addition physics has been for long too isolated from other disciplines in the traditional university training. However physics is a basic science which has a large impact on other domains from which it should not be disconnected. For instance coupling physics and engineering could greatly enlarge the potential attraction of physics. Similarly the applications of physics to biology and biomedicine would appeal to many students. One could think of a double cursus including both physics and the life science, with the possibility for students to choose either at the end of their studies or to change orientation before completion. It should even be worth considering the elaboration of university multidisciplinary programmes around energy and environment issues. Altogether physics has a larger role to play in society and should consequently build up new partnerships with other fields of science. ■

VIEWS FROM

PRESIDENTS KROO AND SCHOPPER ››› 40YEARS OF EPS

MEMORIES OF MY LIFE WITHIN EPS

Norbert Kroo (Hungary),
EPS President, 1993-1995

▲ Norbert Kroo

In 1972 Prof. George Szigeti, the President of the Roland Eötvös Physical Society (Hungary) invited me, at that time a young physicist, to an eye-to-eye conversation on European physics. He started by expressing his belief that sooner of later Europe would be united and Hungary would be part of it. Those who remember that period of European History will agree with me that that vision looked anything but realistic at that time.

He added also that a united Europe needed an organization of European flavor in physics, too, and this was the European Physical Society. He offered me the opportunity to represent Hungarian physics and our Society in the Council of EPS. The offer surprised me but his strong belief convinced me and after a few days of hesitation I accepted his invitation.

That is how my EPS career started and with many years of experience behind me I still think that my decision was sound. At the beginning, in addition to expressing the views of someone rooted in Central-European culture, I could learn the way my West European colleagues thought and later I could help harmonize it with our Eastern traditions, first of all in scientific thinking. EPS did a great job in helping physicists living and working behind the Iron Curtain to keep in contact and cooperate with colleagues on the other side of the Curtain. To be part of this venture has been a great privilege for me and the experience gained in this period helped me later, in the early nineties to act in my official EPS duties, *e.g.* in pulling down some of the barriers between physics in the East and West of Europe created by the Iron Curtain that had existed for more than four decades.

I started my EPS activity in the Council in the seventies, as a member of the Executive Committee in the eighties, and as president-elect, president and past president in the first part of the nineties. This latter was the period of the difficult transition of the former COMECON countries from Communism to Democracy, from planned to market economy. The borders started to melt down and in the more fortunate part of Europe there has been a lot of goodwill and enthusiasm to help the newcomers catch up. EPS started this activity earlier than perhaps anyone else, being one of the forerunners of European integration.

It was clear for us already at that time that a united Europe needed not only an organization in physics on the European scale, but a European Research Council as well, financing basic research on the ▶

basis of Europe-wide competition, with a single selection rule, *i.e.* excellence. It took more than a decade to realize this dream, but finally we started to build up this Council based on the finances of the Ideas specific programme of the 7th Framework Programme with a not yet satisfactory but nonetheless sizeable financial back-up, namely 7.5 billion €. Since this Council is not only a grant awarding organization but a body authorized also to shape European science policy by the activity of its leading body, the Scientific Council, it is in line with our dream and still existing ambition in EPS to shape European science policy for the future.

One of the problems with EPS has for a long time been that the pool of good ideas waiting for realization has always been larger than that of available finances. Therefore our activity depended strongly on sponsors. Individuals, the business world, national and international institutions were approached to support our activities.

The European Commission has been one of the sponsors from the early times of the existence of our Society. The support came mainly for the organization of various conferences. One of the new ideas was the Student Mobility Program. The idea was to send selected physics students from one university in one country to another university in another country for one or two semesters. The universities involved in the program would mutually recognize the credits of the student and tuition fees in the host university would be waived. We succeeded in convincing the European Commission to finance this program but it could be done only within the borders of the European Union.

EPS membership, however, has been broader from the very beginning than the Union and the idea to cover the total European family lacked the necessary financial support. That was the point when Hungarian-born billionaire George Soros and his Open Society Programme came to our help. I succeeded in convincing him in a short time to finance the launch period by covering the expenses of students coming from the non-EU member East-Central and East-European countries. The support EPS received from this generous philanthropist has been in the order of half a million US$. We should still be grateful to Mr. Soros for helping us to extend this program to contribute to the integration process that has led a decade later to the EU membership of most of the countries involved.

Another problem was the visibility of EPS within and outside the scientific community. The EPS label on a series of European science journals where a set of rules had to be followed was useful for this purpose but a journal of its own was the real target to be realized. After a slow start, Europhysics Letters turned out to be a success, increasing the visibility and improving the finances of the Society. It is still a broadly recognized and much-used journal first of all in condensed matter physics.

In the early nineties the attention of the European Commission started to scale up the activity in competitive research funding (programmes, networking, support of work at large facilities and the Marie Curie scholarship program). There was an idea on the table that EPS could take over part of the physics-related programs to be managed on the basis of a contract with the European Commission. The technical details and the professional content were successfully cleared, but unfortunately due to the resistance of the financial authorities of the EU the idea perished before the contracting process started. My feeling is that that failure was a great loss not only to EPS but to the whole physics community.

Europe and the European research landscape have changed significantly in the last few years. During my presidency we were asked to write a supporting letter for LHC and now it is about to start its operation. Several of the member countries from East-Central and Eastern-Europe are now within the Community and we are together working on a homogenized, competitive European Research Area. And EPS with its 40 years history is an efficient, active and strong organization participating in all the important events of the pan-European research effort.

I wish for our Society further fruitful and intellectually challenging years, ■

A NEW HOME FOR THE EPS

Herwig Schopper (Germany),
President of the EPS (1995-1997)

▲ **Herwig Schopper**

How fast time runs - EPS has now existed for 40 years and is in great shape! However, during this period EPS has gone through highs and lows. When I was elected President in 1995 I considered it a great privilege to be entrusted with such an important task enjoying the confidence of my European colleagues. However, having served on the Executive Committee for several years I was also aware of the looming problems.

Indeed when Norbert Kroo handed over to me the presidency he stressed that a restructuring was needed and a new phase had to be initiated. He emphasised the importance of strengthening the Society's Divisions and Groups, its visibility and its capacity to handle professional matters, notably concerning education and applied physics. An interdivisional Group for Applied Physics and Physics in Industry was established and started its successful work chaired by Peter Melville (Birmingham). Norbert Kroo had already improved effectively the contacts between colleagues in East and Western Europe and this activity was intensified by creating a group for East-West cooperation. I managed to persuade Nadrchal (Prague) to chair this group. Achieving a stronger involvement of the National Societies in the East European countries was one of the tasks that was very close to all our hearts. Fortunately this is an issue that has been solved in a way that we would not have dared to dream of in those days. Who would have thought that in 2008 most of the East European countries would be fully integrated into the EU! The EPS can be proud to have contributed to the perforation of the 'iron curtain' and one essential 'tool' was the EPS Office at Budapest. I remember with great pleasure Maria Lazar who served as a devoted, faithful and loyal secretary at Budapest for many years.

With less pleasure I realised rather soon that my main problem as President would be rather down to earth. EPS was criticised by some of its Member Societies that its operations were not cost effective and hence National Societies were not willing to maintain or even increase their contributions. EPS was having persistent deficits, too little funds were available to cover on-going activities and no money could be found for new activities.

An inspection of the cost structure revealed immediately that the expenses for the Secretariat, located in Geneva were too high. The Secretariat had been managed for many years with great competence by Gero Thomas and was intimately interwoven with the editorial office of European Physics Letters operated by Edith, Thomas's wife. A careful evaluation revealed that it was impossible to achieve essential savings by streamlining the operation of the Secretariat, since the main expenditures were the rent for the offices and the salaries, relatively high because of the living cost in Geneva. Therefore after long and extremely difficult discussions it was decided to transfer the Secretariat to another country and National Societies were encouraged to come forward with proposals. Thanks to Claude Sébenne an attractive offer was obtained from the Université de Haute Alsace at Mulhouse, France. Not only the University but also the local authorities were in favour of accepting EPS since they were guided by a policy to attract more European organisations to the region.

Complicated but fruitful negotiations followed concerning mainly the accommodation of the EPS headquarters. A new building was envisaged as a final solution which would house the physics Department of the university and EPS and in that way a better symbiosis between EPS and the university was hoped for. As a temporary solution the EPS was offered office space in a building of the Technopole de la Mer Rouge, a technology campus unfortunately not very close to the university.

Such a fundamental decision as moving the headquarters required a two-thirds majority of the EPS Council. This was not easy to achieve since quite a number of colleagues doubted that the move would yield the expected financial results but rather feared that a well-established office would be lost. Finally at a Council meeting at Lisbon on 22/23 March 1996 the necessary amendments to the EPS Constitution were narrowly approved. This was achieved thanks to the strong support of Secretary J-Ph. Ansermet (Lausanne) who had taken care of the staff problems and J. L. Lewis (UK) who as treasurer assured Council that the move would produce savings, albeit only beyond the period of additional expenses for the move. The move of the EPS headquarters to France provided also a reason for Council to decide to change the currency of the unit fee from Swiss francs to ECU in order to reduce the harmful effects of the strong Swiss francs on the budget and on members'fees.

After further negotiations with the President of the University, Prof. G. Prado, and representatives of the city of Mulhouse a formal agreement was signed in May 1996 and at the beginning of 1997 the EPS office moved. The first Council meeting took place at Mulhouse on 21/22 March 1997 in the Council chamber of the University where it was welcomed by university president Prof. Gresser. In his speech he expressed the hope that the EPS office could move later to the university campus, which indeed happened even though it took longer than originally expected.

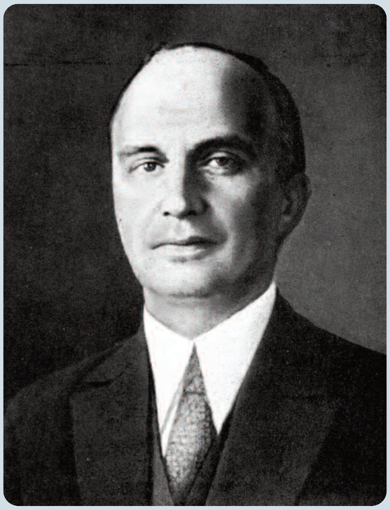
Unfortunately the EPS office staff was not prepared to leave Geneva, except for Gero Thomas who, until his retirement in August 1997, in great loyalty to EPS agreed to organise the building up of a practically new Secretariat with new staff. To our regret the Europhysics Letters partnership, however, decided to keep the journal's editorial office in Geneva.

In the end it turned out that the expectations related to the move were fulfilled. No deficit appeared anymore in 1996 and for 1997 some free money became available. Among other things these measures became the basis for the implementation of a new Strategy Plan which I could present to Council and which was accepted. In 1999 Secretary General, David Lee, who eventually had followed Gero Thomas and who since then serves EPS with the same engagement, could report that EPS was entering into a more active phase. The budget had a positive balance of EUR 100.000 at the end of 1998 and in 1999 the spending could be increased by 20%. New activities could be started with additional personnel, e.g. developing a better conference service for Divisions, or a full-time staff position for communication with members.

This stormy period is now part of history but thanks to the engagement and solid work of many colleagues in the Executive committee, in Council, in the Divisions and other parts of EPS it became an essential element of revitalization so that today we can celebrate the 4^{0th} anniversary of a strong and efficient EPS. ■

Erratum

In the article on L.V. Shubnikov and the 70 years of type II superconductors, Europhysics News 39/3, p.35, the picture of A. V. Shubnikov was published by mistake. Here is the picture of L.V. Shubnikov. ■



GERO THOMAS MEDAL 2008 »» AWARD

The laudation by the EPS President F. Wagner

Gero Thomas was the Secretary General of the EPS from 1973 to 1997 and played an essential role in the growth and development of the Society. He guided the Society through its early years and contributed greatly to establishing its financial stability. During his 24 years as Secretary General, Gero Thomas collaborated with 12 Presidents. Many new Member Societies, particularly from Eastern and Central Europe joined the EPS during this time. He was attentive to the needs of the members, always willing to help in anyway he could, both professionally and personally. His lasting achievements include obtaining a $ 500,000 grant from the Soros Foundation for student mobility in Europe, the establishment of the Budapest Secretariat, the creation of EPL, Europe's flagship letters journal, and the successful relocation of the Secretariat from Geneva to Mulhouse. The Gero Thomas Medal was created in 2000 to honour in his memory, and his contributions to EPS and is given to individuals for outstanding service to the Society.

The recipient of the 2008 Gero Thomas medal is **Prof. Dr. George Morrison**. He is a nuclear physicist who obtained his degree at Glasgow University. George is a noticeable Scotsman. He has worked at AERE, Harwell, interrupted by an extended stay at the University of Chicago, and after at Argonne National Laboratory and in Paris before he became Professor at Birmingham University. He served the university as Deputy Dean, as Dean and as Head of the School of Physics and Astronomy.

George has had close connections with EPS for more than 30 years – a time equivalent to more than 12 presidents. He started as a member of the Nuclear Physics Division, continued as a member of the Executive Committee and thereafter he involved himself deeply in EPN, Europhysics News, the society bulletin, first as chairman of the Editorial Board, then as Editor and thereafter as Scientific Editor at the side of Claude Sébenne, the present Editor of EPN. George has now handed over this responsibility to Jo Hermans at the beginning of April.

The EPS honours George Morrison for his sustained contributions to the society. In all areas of his involvement, George has been respected as a member whose influence lay with his charm and the way that he says what he thinks. In all stages of his EPS "career", George always had in mind the benefit of the society. Most observable is the development of EPN in the recent years as an interesting, attractive and topically well-balanced journal.

The Executive Committee awarded unanimously the Gero Thomas medal to George.

▲ George Morrison

The reply by the recipient, George Morrison:

"You have heard from Fritz what I have 'put in' to EPS – let me now say briefly what I have 'got out' of it!

First was the opportunity to travel. I have always found travel, although not too far, stimulating - travel to Executive and Council meetings sited in interesting locations, to EPN Production Team meetings in Paris, and to Mulhouse itself.

Second was the opportunity to meet 'interesting' people -

a) members of the EPS Council and Boards and in particular the EPS presidents. Each president has been different in style but all have been committed to advancing EPS. I am personally grateful to each for their support. And EPS should also be grateful for how much they bring to EPS and the time that they put in on its behalf.

◄ The Gero Thomas Medal

b) members of the EPS office and the support received – particularly from David Lee and Sylvie Loskill – my thanks to them. In every respect David has been a worthy successor to Gero. And my relation with Sylvie has always been a pleasure – her phone calls and her emails have always 'made my day'.

c) lastly, but not least, my EPN colleagues – members of the Editorial Board, Claude Sébenne now EPN editor and Xavier, the graphic designer, whose influence on the design and layout of EPN is for all to see. My good wishes go to them and to my successor Jo Hermans – whom you will recognise as the regular EPN author of 'Physics in Daily Life'. However, I will not be making a clean break with EPN – too traumatic – having been invited to remain on the Editorial board and to continue to bring, as a Scotsman, my English to bear in the editing of EPN.

Finally I would conclude by thanking the Executive Committee for the honour they have done me. I much appreciate the recognition of my efforts that the medal confers – efforts that have in the main been a 'labour of love'. ■

PHYSICS ON COURSE TO BOLOGNA »» EDUCATION

Gerd Ulrich Nienhaus (DPG, Germany)

This survey of the Konferenz der Fachbereiche Physik (KFP, German Physics Faculties' Conference) provides an overview of the implementation of the new Bachelor and Master degree courses in Germany. It appeared originally in Physik Journal 6 (2007) Nr. 10 and has been translated by M. Dietrich and A. Lochau.

The Bologna Process has launched extensive reforms of the university study courses in Germany. By 2010, essentially all previous physics courses of study will be replaced by Bachelor and Master courses throughout the country, including professional physicist (diploma degree) and physics teacher (state examination) programmes. In May 2005, the Konferenz der Fachbereiche Physik (KFP, German Physics Faculties' Conference) issued recommendations for the new Bachelor and Master curricula in physics [1]. A detailed survey about the progress of the transition and organization of the new programmes within the German physics faculties was made in June 2007; it provides an overview of the development. The following is a summary of the results.

In the Bologna Declaration of 1999, the European countries – there are presently 46 member states – agreed upon the creation of a common European higher education area by 2010 [2]. An essential objective of the development of a European network of university education is to create transparent and comparable academic degrees, thereby furthering the international competitiveness, employability and mobility of students and graduates.

Fundamental elements of the Bologna Process are:

- Implementation of a two-stage system of curricula (Bachelor/Master) that comprise topically defined modules with credit points (CP) that reflect the effort required to meet the goals of the the courses.
- Introduction of standards and guidelines for quality assurance to ensure national and European comparability of modules and degrees.

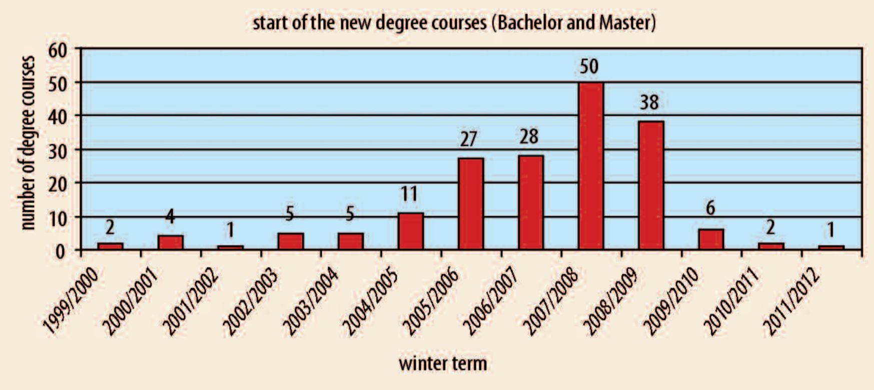
Implementation of the Bologna Process demanded a reorganization of the physics programmes to conform to the Bachelor/Master system, which initially generated controversial discussions among physicists, since the Diploma degree in physics had been appreciated for decades as a "trademark" by science and economy, both at home and abroad. This is also reflected by the low unemployment rate of physicists that was only slightly above three per cent in 2006 [3].

For many years, KFP had the important function to coordinate the standards of physics degree programmes in order to ensure comparable quality standards throughout Germany. In 2005, KFP passed guidelines for the organization of the new Bachelor/Master curricula at German physics faculties. According to these recommendations, the Bachelor course shall impart a broad, general physics education in six semesters and ensure a fundamental professional qualification. On this basis, the consecutive, four-semester Master course offers specialized knowledge in sub-disciplines of physics and leads to an education at the highest international level. An overall one-year research period shall qualify the student for independent scientific work. The Master degree is comparable to the present Diploma and is the standard entry degree into a PhD program.

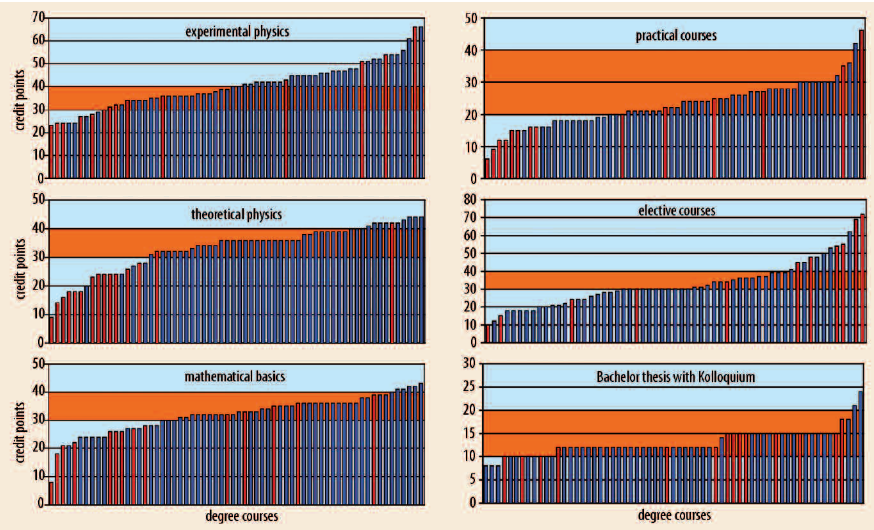
Successful snap-shot

The conversion of the physics programmes at German universities is currently in its critical phase (Fig. 1). For the winter semester 2007/2008, the majority of the physics curricula have already been turned into Bachelor/Master degree courses. This process shall be finished by 2010 and, therefore, this milestone of the Bologna Process will be met. In the summer term 2007, the reform process had proceeded sufficiently far that the time was ripe for a first assessment. To this end, the KFP Executive Board developed a questionnaire for collecting data about the planned and already realized curricula (professional physicists' courses, teachers' education, and trans-disciplinary courses with their main focus on physics). Besides organizational questions (*e.g.*, type/name of the course, date of conversion, capacity, accreditation, language of instruction, admittance tests), this questionnaire contained mainly questions about the content of the courses (emphasis on the sub-disciplines within physics, mathematics, lab courses, voluntary courses, final theses).

53 physics faculties at German universities (of a total of 58) provided data on 184 courses which included 50 courses for physics teachers. Consequently, a nearly complete snap-shot of the conversion to Bachelor/Master degree physics courses at German universities has been ▸



◀ **FIG. 1: The restructuring of the new courses hits its peak in the winter semester 2007/08.**



▲ **FIG. 2: Compared with the explicit physics courses (blue), courses with special titles (red) diverge more from KFP recommendations for the Bachelor (orange band) programme.**

attained. The main focus of this report is on the professional physicists' courses. The survey on physics teachers' courses yields a very heterogeneous pattern which is not suitable for a comprehensive report. The legislation of Universities is within the responsibilities of the individual states in Germany's federal system and, apparently, there are largely different notions among the federal states about the implementation of the transition.

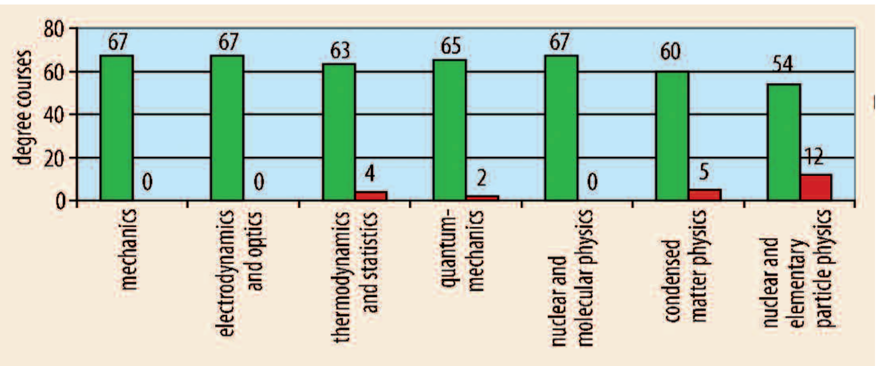
Bachelor courses

All registered Bachelor courses comprise six semesters each. 50 courses lead to the university degree "Bachelor of Science" (all participating faculties except one intend to offer this degree). Additionally, there are 13 courses with special titles which are in many cases interdisciplinary in character. Nevertheless, they have their focus on physics, e.g., physics in computer sciences, materials science, and physics in economy (4). Moreover, the faculties reported 22 Bachelor courses for physics teachers. Each topical course consists of 22 modules on average. 87 per cent of the courses consist of 15 to 30 modules.

According to the KFP recommendations, key curricular activities should be represented in the new courses with specific weighting factors (see table). Figure 2 shows that the faculties mainly followed these recommendations while realizing the Bachelor course (without teaching). Significant variations are noted only for the category "experimental physics", for which 45 per cent of the courses allocate more than the recommended 40 credit points. Red columns denote special courses with focus on physics. They are predominantly found at the edge, as they may deviate from the norm due to their non-physics components. Apart from some exceptions, 10 – 15 credit points are assigned to the Bachelor thesis. In the elective courses, the overall number of credit points ranges between 10 and 70. Here, more than 50 per cent of all courses deviate from the KFP recommendation. In the vast majority of Bachelor courses, the essential fields of physics – mechanics, electrodynamics, optics, thermodynamics, statistics, nuclear and molecular physics, physics of condensed matter, nuclear and elementary particle physics as well as quantum mechanics – are covered as recommended (Fig. 3). Pronounced deviations can only be found in nuclear and elementary particle physics. However, seven out of the twelve courses without this topic belong to courses with special orientation.

The comparison of the Bachelor courses allows one to conclude that similarly designed physics courses will exist within Germany so that a similar knowledge standard and proficiency level of the graduates can be anticipated.

▼ **FIG. 3: Most Bachelor courses cover the major sub-disciplines of physics.**



Master courses

A total of 94 Master courses were reported, 91 of them consecutively build upon the Bachelor degree; 91 are designed for four semesters. 42 of these courses lead to a Master degree in physics; another 24 courses have a topical orientation in, for example, astrophysics, biophysics or technical physics (4). Thus, the relative fraction of these specialized courses is much higher than at the Bachelor level and reflects the anticipated specialization in the Master course. Nearly 90 per cent of the professional physicists programmes were classified as research-oriented rather than application-oriented. 28 of the Master courses are for physics teachers. Concerning the educational content, KFP recommended that Master courses should be designed in such a way that they consist of a one-year advanced study phase followed by a one-year research period during which the Master thesis has to be written (table). The graphs in Fig. 4 show very broad distributions of the credit points in the three categories: experimental and theoretical physics as well as voluntary and advanced study courses in the advanced study phase. Apart from a few exceptions, the reference points for experimental and theoretical physics were met. For the electives and advanced study courses, the enormous bandwidth of 5 – 74 credit points reflects the increasing specialization in the curricula. The research period consists of introductory modules with a total of 30 credit points, followed by the actual Master thesis with another 30 credit points. The faculties followed the KFP recommendation for the creation of four-semester Master courses with only one exception.

Further aspects of the reform

It is a distinct aim of the Bologna Process to encourage mobility and the development of international networks. Interestingly, German remains the language of instruction for the majority of the registered courses; only 11 are taught in English and 22 are bilingual.

In the framework of the Bologna reform, miscellaneous tools are foreseen for the quality management of university study courses. First of all, an entry examination may be required for admittance, which is the case for only 37 per cent of the Bachelor and Master courses. In the past, physics classes were rarely overcrowded, so that an initial restriction of admittance may not be desirable. Rather, many faculties intend to counteract proficiency deficits of students entering the programmes at an early stage by keeping strict progress control and offering student tutoring, in addition to the course-related module exams. In this way, one aims to keep the drop-out rate of students at a minimum. Many possibilities of early consulting (tutorials, mentoring) as well as monitoring (examinations to help orientation, number of credit points at certain study stages, examinations across the modules) are foreseen.

Not only are the students continuously assessed, but also the courses themselves are inspected within the accreditation by independent external agencies, e.g., ASIIN. At present, 59 Bachelor and Master courses in physics have gone through this procedure and, so far, no course has been refused accreditation. Another 38 courses are amidst the process of accreditation; 58 courses are presently in preparation for accreditation. In the meantime, the replacement of program accreditation by system accreditation is being discussed. Reasons for this development are, amongst others, the tremendous expenditures involved. While each single course is reviewed in a program accreditation, system accreditation reviews primarily the implementation of internal quality control management within a university. Already ten faculties aim at a system accreditation.

Clear profile for career opportunities

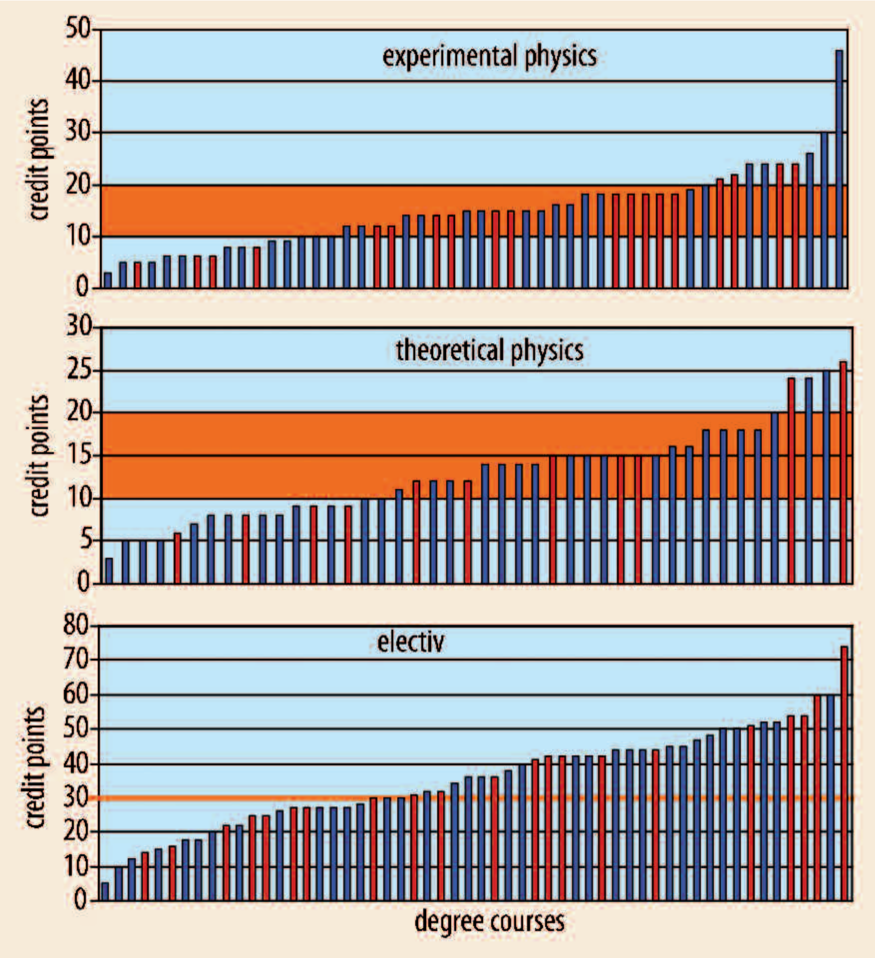
The character of the discipline "physics" defines itself by the kind of academic education in this subject. Therefore, it is understandable that the study reforms caused by the Bologna Process have been discussed passionately and controversially among the physicists. The physics faculties utilize the transition to the Bachelor/Master scheme judiciously to adjust their courses to the constant changes within the field as well as to adapt them to an ever-changing environment. The data presented here offer an outlook on the future development of physics university studies in Germany.

The guidelines of the Bologna Process require the Bachelor degree to be the first degree representing a professional qualification. Indeed, the Bachelor curricula in this survey cover all essential fields of physics and impart knowledge which is necessary for job qualification. To realize this goal, courses which usually cause problems for the students (mathematics, theoretical physics) are arranged in a temporally more concentrated manner during the six semesters of the Bachelor courses as compared to the traditional Diploma courses. This problem requires special attention by the faculties to keep the drop-out rate as low as possible. As the structure of the Bachelor courses is quite tight, it may lead to longer overall study periods if students have to repeat courses.

In the Bachelor education, an in-depth exploration of subfields of physics and, particularly, a longer research period are absent. These curricular activities already provide students with job experiences; they were a significant part of the previous (Diploma) physicist education and were likely responsible for the high attractiveness of physicists on the job market. It is for this reason that KFP and the Deutsche Physikalische Gesellschaft (DPG, German Physical Society) (5) recommend physics students to complete ▶

KFP RECOMMENDATIONS FOR THE STRUCTURE OF PHYSICS DEGREE PROGRAMMES	
BACHELOR PROGRAMME	
lectures / tutorials in experimental physics	30 – 40 CP
lectures / tutorials in theoretical physics	30 – 40 CP
lectures / tutorials in mathematical basics	30 – 40 CP
basic lab course	10 – 20 CP
advanced lab course	10 – 20 CP
elective lectures / tutorials	30 – 40 CP
Bachelor thesis with colloquium (max. 3 months)	10 – 20 CP
Total:	180 CP
MASTER PROGRAMME	
advanced study phase:	
lectures / tutorials in experimental physics	10 – 20 CP
lectures / tutorials in theoretical physics	10 – 20 CP
elective and advanced courses (lectures, project/advanced lab courses, tutorials)	30CP
research phase:	
introductory modules	30 CP
Master thesis	30 CP
total:	120 CP

CP = credit points



▲ **FIG. 4: During the one-year advanced studies period of the Master course, the electives show an enormous range of credit points (orange: KFP recommendation).**

▸ their education by continuing in a consecutive Master course. Our survey reveals that the student capacity in the Master programmes will be one-third less than in the Bachelor programmes. Assuming that one third of the entering freshmen will drop out of physics, there will, however, be enough room for the remaining students to continue toward a Master degree.

The examination modalities will experience a fundamental change by adapting to the Bachelor and Master system. In the spirit of an efficient study progress, the Bologna Reform is asking for course-related module examinations so as to continuously provide feedback to the students concerning their level of achievement. Thereby, students have the possibility to realize and compensate their deficits instantly. Within the Diploma courses, such exams were already established in the form of numerous written tests. However, exams covering a broad range of topics, as was the case in the intermediate Diploma and final Diploma examinations, will no longer exist. Some professors are concerned that the students may only concentrate in future exams on narrowly focused topics, and that they may no longer acquire a broad view across the subfields that reveals the coherences of physics. The consequences of these changes should be monitored carefully.

The study reform in physics will replace the Diploma degree by two new degrees. It remains to be seen whether the Bachelor degree in physics will be a success. From the conceptional design of the courses it is evident that the previous Diploma physicist will be replaced by the physicist with a Master degree, with an equivalent professional profile. While a specialization in the Master study is desirable, one should be cautious about too many different titles for physicists' degrees. As with the Diploma, a clear profile of the Master degree in physics largely defines the physicist's profession, and can guarantee excellent chances on the job market for the well-trained and versatile university graduate in physics. ■

Acknowledgement

Many thanks are due to Michaela Roth, Bernd Spindler and André Wobst from the DPG office, our contact persons in the physics faculties as well as the members of KFP Executive Board for their generous support in carrying out this survey.

About the author

Prof. Dr. Gerd Ulrich Nienhaus, University Ulm, is Spokesman of the Konferenz der Fachbereiche Physik (KFP, German Physics Faculties' Conference) and Executive Board Member of the Deutsche Physikalische Gesellschaft (DPG, German Physical Society) for education and training.

References

[1] The exact wording of the decision (in German) can be found at www.kfp-physik.de.

[2] A comprehensive description (in German) is provided by the German University Rectors' Conference (HRK) at www.hrk-bologna.de.

[3] U. Weigelt, *Physik Journal*, (2006), 27.

[4] A comprehensive listing can be found in: G. U. Nienhaus, *Physik Journal*, (2007), 29.

[5] DPG press release 12/2004: "Für eine Neuordnung des Physikstudiums".

Conference announcements

European strategy for astroparticle physics

This Workshop will be held in Brussels, 29-30 September 2008. The Roadmap and Priorities for European Astroparticle Physics large infrastructures will be presented and compared with neighbouring field priorities in Europe (Astrophysics, ESA, ESO, CERN) and the European ESFRI Roadmap for large infrastructures.

›››**Website:**
http://brussels2008.aspera-eu.org

38 YEARS OF THE EPS HIGH-ENERGY PARTICLE PHYSICS DIVISION

>>> DIVISION REPORT

Raymond Gastmans and **Per Osland** (1992-93 and present Chairmen of the HEPP Division)

The HEPP Division was founded in 1970, just two years after the foundation of EPS. The first Board chair was then P. Preiswerk of CERN. The focus of the High Energy Particle Physics Division Board has been its biannual conferences. In 1989, the tradition was started to award high-profile prizes on these occasions.

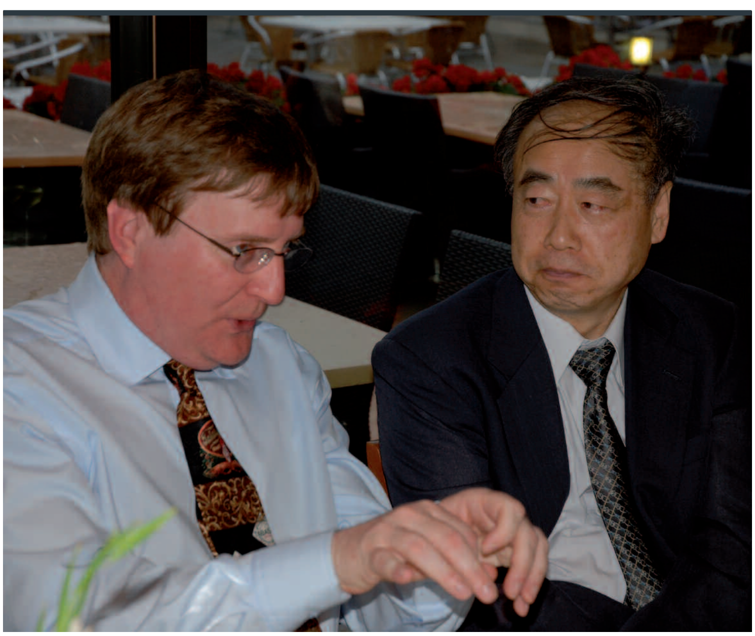
In recent years, the chair tenure has been two years, in phase with the conferences. A full list of chairs is given in Table 1. Since the mid-1970s, the division has also had a secretary (see our web page), effectively a chair-elect. Since the mid-1990s, the division has maintained a web site at http://eps-hepp.web.cern.ch/eps-hepp/, with relevant information for the community, as well as for the board itself, in addition to the site at www.eps.org. The number of individual members (IMs) belonging to the division, has for a long period remained constant, of the order of 600.

The first EPS-HEPP conference was organized in Bologna in 1971, during the "reign" of Preiswerk. At that time, and still today, the EPS conferences take place in odd years, as opposed to the "Rochester" or ICHEP series, which are held in even years. Together with the Lepton-Photon Symposium (LP), also in odd years, these three series have become the major three conferences in the field. The format of the EPS-HEPP conference is that it starts with three days of parallel talks, then a day off (excursion), followed by three days of plenary talks. This is rather similar to the ICHEP conferences, whereas the Lepton-Photon Symposia only have plenary talks. While the ICHEP and LP conferences alternate between America, Europe and Asia, the EPS-HEPP conferences are obviously restricted to a European location. Thus, it inevitably happens that it "collides" with the LP Symposium when that one takes place in Europe. This dilemma was solved in 1991 by merging the two. The HEPP Board also attempts to stimulate science policy discussions at the conferences, by devoting a plenary session, organized jointly with the European Committee for Future Accelerators (ECFA), to presentations on the status and plans of the large laboratories. These have often led to lively discussions.

In view of the many topical conferences that are sprouting everywhere, and the instantaneous broadcasting of new discoveries and ideas on the web, it is not trivial to attract a sizable audience at the EPS conferences. The number of participants may possibly have peaked in the mid-1990s. The attendance at the conferences has recently been of the order of 600, similar to the number of IMs.

In 1989 the division board, which acts as organizer of the EPS-HEP conferences, started awarding the "High Energy and Particle Physics Prize" of the European Physical Society on the first day of plenary sessions. The first awardee was G. Charpak, who went on to receive the Nobel Prize in 1992. In 2003, it was deliberately decided to include non-Europeans in the pool of nominees. In fact, the division has succeeded in maintaining this as a very prestigious prize (list below): about a third of the prize winners have later received the Nobel Prize. Our modest prize money initially came from industry sponsorship, but has recently been ▶

▼ Dave Wark (then chair) and Makoto Kobayashi discussing CP violation



▼ **TABLE 1:** EPS HEPP Board chairs 1970-2008

P. Preiswerk	CERN	1970 - 1972
A. Zichichi	Bologna, Italy	1972 - 1973
G. Charpak	CERN	1975
G. Marx	Budapest, Hungary	1976 - 1977
G. Preparata	CERN	1978 - 1981
J. Charap	London, UK	1981 -1984
R. Salmeron	Palaiseau, France	1984 - 1988
W. Bartel	DESY, Fed. Rep. Germany	1989 -1991
R. Gastmans	Leuven, Belgium	1992 -1993
G. Jarlskog	Lund, Sweden	1994 -1996
W. Kummer	Vienna, Austria	1997 -1999
G. Mikenberg	Rehovot, Israel	1999 - 2001
M. Spiro	IN2P3, Paris, France	2001 - 2003
J. Bernabeu	Valencia, Spain	2003 - 2005
D. Wark	Rutherford, UK	2005 - 2007
P. Osland	Bergen, Norway	2007 -

supplemented by interest gained on funds accumulated from paid conference fees.

In 2001, three additional prizes were introduced: the Outreach Prize, the Gribov Medal and the Young Physicist Prize.

High Energy and Particle Physics Prize of the European Physical Society

1989: **G. Charpak**, for the development of detectors: multi-wire proportional chambers, drift chambers and several other gaseous detectors, and their applications in other fields

1991: **N. Cabibbo**, for his fundamental contribution to the theory of weak interactions leading to the concept of quark mixing

1993: **M. Veltman**, for his pioneering work on the role of massive Yang-Mills theories for weak interactions

1995: **P. Soeding, B. Wiik, G. Wolf, S.L. Wu**, for the first evidence for three-jet events in e+e- collisions at PETRA

1997: **R. Brout, F. Englert, R. Higgs**, for formulating for the first time a self-consistent theory of charged massive vector bosons which became the foundation of the electroweak theory of elementary particles

1999: **G. t'Hooft**, for pioneering contributions to the renormalization of non-abelian gauge theories including the non-perturbative aspects of these theories

2001: **D. Perkins**, for his outstanding contributions to neutrino physics and for implementing the use of neutrinos as a tool to elucidate the quark structure of the nucleon

2003: **D. Gross, H. Politzer, F. Wilczek**, for their fundamental contributions to quantum chromodynamics, the theory of strong interactions

2005: **H. Wahl** and the **NA31 collaboration**, for his outstanding leadership of challenging experiments on CP-violation, and for their showing for the first time direct CP-violation in the decays of neutral K-mesons

2007: **M. Kobayashi, T. Maskawa**, for the proposal of a successful mechanism for CP-violation in the standard model, predicting the existence of a third family of quarks. ■

▼ **TABLE 2:** International Europhysics Conference on High-Energy Physics

1	Bologna, Italy	April 14-16, 1971
2	Aix-en-Provence, France	September 6-12, 1973
3	Palermo, Italy	June 23-28, 1975
4	Budapest, Hungary	July 1-9, 1977
5	Geneva, Switzerland	June 27 - July 4, 1979
6	Lisbon, Portugal	July 9-15, 1981
7	Brighton, UK	July 20-27, 1983
8	Bari, Italy	July 18-24, 1985
9	Uppsala, Sweden	June 25 - July 1, 1987
10	Madrid, Spain	September 6-13, 1989
11	Geneva, Switzerland (*)	July 25 - August 1, 1991
12	Marseille, France	July 22-28, 1993
13	Brussels, Belgium	July 27 - August 2, 1995
14	Jerusalem, Israel	August 20-26, 1997
15	Tampere, Finland	July 15-21, 1999
16	Budapest, Hungary	July 12-18, 2001
17	Aachen, Germany	July 17-23, 2003
18	Lisbon, Portugal	July 21-27, 2005
19	Manchester, UK	July 19-25, 2007
20	Krakow, Poland	July 16-22, 2009

(*) The Geneva EPS conference was merged with the Lepton-Photon Symposium

The Outreach Prize

2001: **C. Sutton, E. Johansson**
2002: **M. Kobel**
2003: **N. Tracas**
2003: **R. Landua**
2004: **A. Pascolini**
2005: **D. Barney, P. Kalmus**
2007: **R. Jacobsson, C. Timmermans**

The Gribov Medal Prize

2001: **E. Gubser**
2003: **N. Arkani-Hamed**
2005: **M. Zaldarriaga**
2007: **N. Beisert**

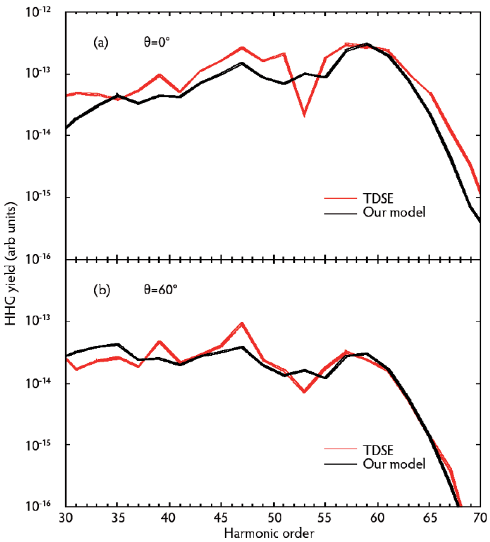
The Young Physicist Prize

2001: **A. Quadt**
2003: **G. Unal**
2005: **M. de Naurois**
2007: **I. Furic, G. Gomez-Ceballos** and **S. Menzemer**

HIGHLIGHTS FROM EUROPEAN JOURNALS

Ultrafast self-imaging of molecules under intense laser pulses

X-ray and electron diffractions are powerful tools for spatial imaging of structure at the atomic level, but they lack the temporal resolution needed for studying chemical transformations. Today infrared laser pulses of a few femtoseconds duration are widely available but their wavelengths are much too long for spatial imaging. However, when a molecule is exposed to an intense laser pulse, electron(s) that are released earlier by tunneling ionization may be driven back by the laser field to recombine with the molecular ion to emitted high energy photons, in a process called high-order harmonic generation (HHG). Since photo-recombination is the reverse of photo-ionization, which is the traditional tool for studying the structure of molecules, the emitted HHG spectra may be used for self-imaging of molecules, with temporal resolution of a few femtoseconds.



◄ **Comparison of HHG spectra at two alignment angles using our model against direct quantum calculations (TDSE).**

To demonstrate how this scheme works, we showed that accurate HHG spectra obtained for H_2^+ are well reproduced as the product of a returning electron wave packet with the photo-recombination cross section. This established the theoretical foundation that laser-induced HHG spectra of a molecule can be used to extract photo-ionization cross sections. Since the latter are very sensitive to the atomic arrangement in a molecule, accurate spatial information can be retrieved, thus proving the promise of using laser-induced HHG for ultrafast time-resolved imaging of transient molecules. ■

A.T. Le, **R. Della Picca**, **P. Fainstein**, **D. Telnov**, **M. Lein** and **C.D. Lin**, "Theory of high-order harmonic generation from molecules by intense laser pulses", *J. Phys. B: At. Mol. Opt. Phys.* **41**, 081002 (2008)

Black holes in a water channel

Black holes are some of the most mysterious objects in the Universe, but scientists at Nice and St Andrews have created analogues of black holes in a water channel. Here they observed a vital indication for Stephen Hawking's prediction that black holes are not black after all.

Black holes resemble cosmic drains where space disappears in their singularities like water going down a plughole. Space seems to flow, and the closer one gets to the black hole the faster it flows. At the event horizon space appears to reach the speed of light, so nothing, not even light, can escape.

The team, led by Germain Rousseaux and Ulf Leonhardt, made horizons in a 30 meter long water channel with a powerful pump on one end and a wave machine on the other. The horizon is the place where the water begins to flow faster than the waves. They sent waves against the current, varied the parameters, and filmed the waves. Over several months the team painstakingly searched the videos for clues. They wanted to see whether the waves show signs of Stephen Hawking's famous prediction that the horizon creates particles and anti-particles.

Of course, flowing water does not create anti-particles, but it may create anti-waves. Normal waves heave up and down in the direction they move, whereas anti-waves do the opposite. As the team report in New Journal of Physics, they observed traces of such anti-waves in their videos. These waves are tiny, but they were still significantly stronger than expected.

Much work remains to be done, but, in any case, the paper shows that something as simple and familiar as flowing water may contain clues of something as mysterious and exotic as the physics of black holes. ■

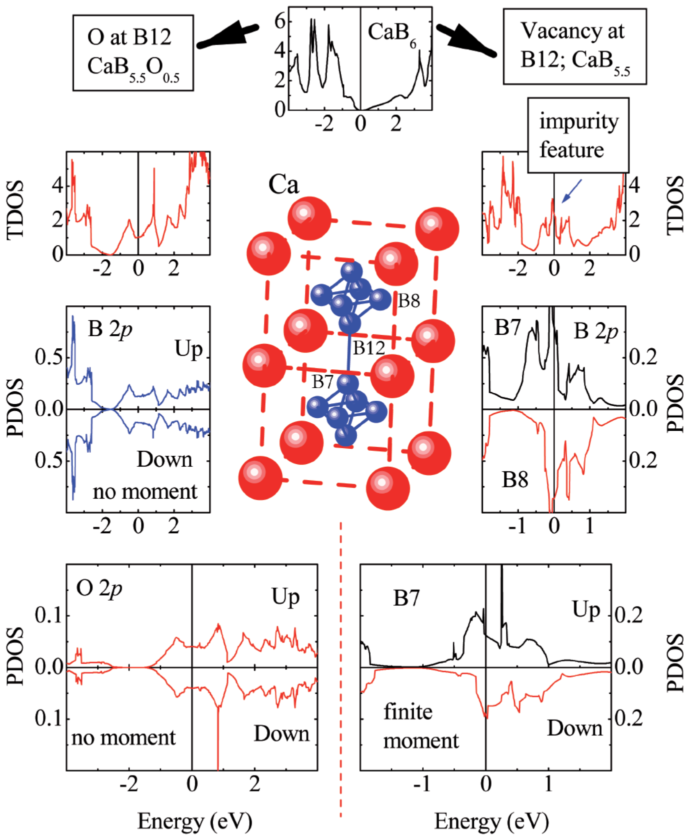
Water-wave horizon ►

G. Rousseaux, **C. Mathis**, **P. Maïssa**, **T. G. Philbin** and **U. Leonhardt**, "Observation of negative-frequency waves in a water tank: a classical analogue to the Hawking effect?" *New J. Phys.* **10**, 053015 (2008)

Ferromagnetism in non-magnets

Ferromagnetism is the most remarkable property of matter that holds the key to our daily life and the future of technology. Ferromagnetism depends on two entities; (i) magnetic moment and (ii) delocalized electrons that couple them. Almost all the magnetic materials consist of elements having partially filled *f* (Eu, Gd, Tb, Dy, *etc.*) or *d* (Fe, Co, Ni, *etc.*) bands among highest occupied energy bands. Small radial extension of *f*-orbitals in rare-earths makes them highly localized leading to finite magnetic moment and coupling occurs via the interaction of these moments with conduction electrons. The *d* electrons have *both*; magnetic moment due to strong electron-electron Coulomb repulsion and itineracy that mediates magnetic coupling.

Surprisingly, CaB_6 exhibits ferromagnetism (Curie temperature > 600 K), despite the absence of partially filled *d* or *f* band element! Pure CaB_6 is a non-magnetic semiconductor (band gap ~ 0.2 eV). As demonstrated in the figure, the non-magnetic impurities such as carbon/oxygen do not generate magnetic moment in CaB_6. Interestingly, vacancy in boron sublattice leads to the formation of an *impurity band* near Fermi level. Such impurity states have B 2*p* character and are located close to the vacancy site. Exchange splitting of these states is finite leading to magnetic moment similar to experimental estimations. This suggests that vacancies/defects usually expected in semiconductors introduce local character in low density conduction electrons and their itineracy mediates the magnetic coupling. This is remarkable as vacancies introduce *d*-like behaviour in *p*-electrons. This suggests that low density of vacancies/defects in such small band gap non-magnetic semiconductors can lead to high temperature ferromagnetism, which is very important for advancement in technology. ■



◄ **Calculated density of states (DOS) and partial DOS (PDOS) of CaB_6, $CaB_{5.5}O_{0.5}$ and $CaB_{5.5}$. It is demonstrated that magnetic moment forms due to removal of B12 rather than replacement of B12 by O.**

Kalobaran Maiti, "Role of vacancies and impurities in the ferromagnetism of semiconducting CaB_6", *EPL* **82**, 67006 (2008)

Frequency spectrum of the Casimir force: interpretation and a paradox

The Casimir effect is the result of quantum fluctuations of the electromagnetic field and causes attractive forces between optically reflecting objects. The Casimir pressure between plates of real materials, important at sub-micron separations, is calculated using a celebrated formula due to Lifshitz involving an integral over all frequencies.

Ford predicted [*Phys. Rev. A* **48** (1993) 2962] that if materials could be found that were good reflectors only in a band of frequencies, much larger and indeed repulsive Casimir forces could be obtained, because the frequency integrand of the Lifshitz formula is wildly oscillating, the net pressure apparently the sum of alternating and almost perfectly cancelling terms, each much larger than the force itself.

However, such an optimistic prediction appears ruled out by a recent experiment in which the Casimir force was measured between so-called hydrogen switchable mirrors that could be made non-reflecting in a band of frequencies only. According to the direct frequency interpretation this perturbation should imply large corrections, but no change was measured as the mirror was switched off.

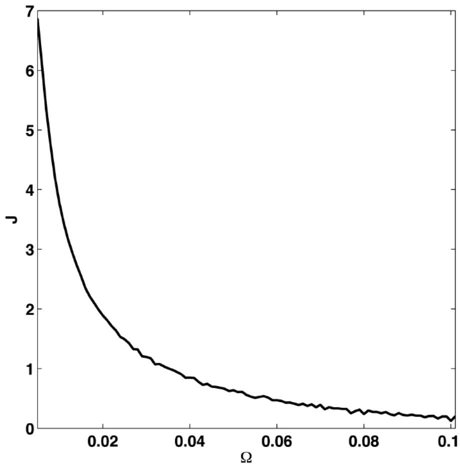
The standard way of calculating the Lifshitz integral is by a Wick rotation to imaginary frequencies. In this formalism, a perturbation of the dielectric response of the materials used is predicted to affect the Casimir force very little, in agreement with experiment. This makes for a paradox, since the two calculation procedures should be equivalent. The resolution of this paradox is important not only because of the technological promise of Ford's predictions within micro-engineering, but for a proper understanding of the frequency spectrum of fluctuation forces. ■

S.A. Ellingsen, "Frequency spectrum of the Casimir force: Interpretation and a paradox", *EPL* **82**, 53001 (2008)

Escaping particles in a periodic potential show giant transient directed transport

Non-integrable dynamics of driven Hamiltonian systems may provide rich diversity of transport phenomena. We illustrate the emergence of a transient giant directed flow of particles evolving in a symmetric, spatially periodic potential. Starting with an ensemble of particles that are trapped in one potential well, escape necessitates chaotic dynamics. The latter is generated by time-periodic alternations of the inclination of the potential by an external ac-field. It has to be emphasized that the system is unbiased in the sense that the force averaged over a period length in time and space respectively vanishes.

Trajectories that become embraced by the arising chaotic layer around the broken separatrix may escape from its trapping region. Interestingly, for adiabatic modulations of the potentials inclination there results a substantial directed flow. Otherwise, for intermediate and fast modulations, the chaotic trajectories are swept across the separatrix layer corresponding to repeated trapping-detrapping transitions. Most importantly, as we demonstrate for adiabatic modulations all particles that manage to escape from the trapping region fly subsequently in a unique direction that is determined by the phase of the ac-field. The unidirectional flow proceeds then over an extremely long time interval corresponding to 15×10^3 period durations of the ac-field and during this transient the particles cover giant distances. Strikingly, the slower the modulation the larger is the gain in momentum of the escaped particles and thus the emerging asymptotic current that is inversely proportional to the modulation frequency. Explanation of this phenomenon are given in terms of the underlying phase space geometry. In particular trapping of the trajectories in ballistic channels contained in the non-uniform chaotic layer serves for long-lasting ballistic motion. ■



▲ The current J versus the driving frequency Ω. The resulting 1/Ω dependence of the current corroborates with the fact that the momentum gain is the larger the smaller is the angular driving frequency Ω.

D. Hennig, **L.Schimansky-Geier** and **P.Hänggi**, "Slowly rocking symmetric, spatially periodic Hamiltonians: The role of escape and the emergence of giant transient directed transport", *Eur. Phys. J. B* **62**, 493 (2008)

Heating of solids to ten million Kelvin by a petawatt laser

An international team of physicists from the EU, Japan and the US has reached a milestone in high energy density physics. They have heated significant volumes of solid density matter to temperatures of 10 million Kelvin using intense laser pulses from the Vulcan petawatt laser facility at the STFC Rutherford Appleton Laboratory, UK.

Previously only ultra-thin layers of matter (less than 1-micron thick) had been heated to similar temperatures. A reasonable volume of matter is needed to initiate fusion reactions to enable energy gain. This made the previous measurements interesting, but of limited value for applications since the expansion of the material inevitably introduces density variations. This new work confirms that the heated material stays at this temperature and at solid density for a least 20 picoseconds – which is more than enough time for high-speed instruments, such as time-resolved X-ray spectrometers, to probe the heated material. *"This is an exciting development – we now have a new tool with which to study really hot, dense matter. Careful selection of the target parameters allows access to this new regime"* said Peter Norreys (STFC Rutherford Appleton Laboratory and Imperial College London).

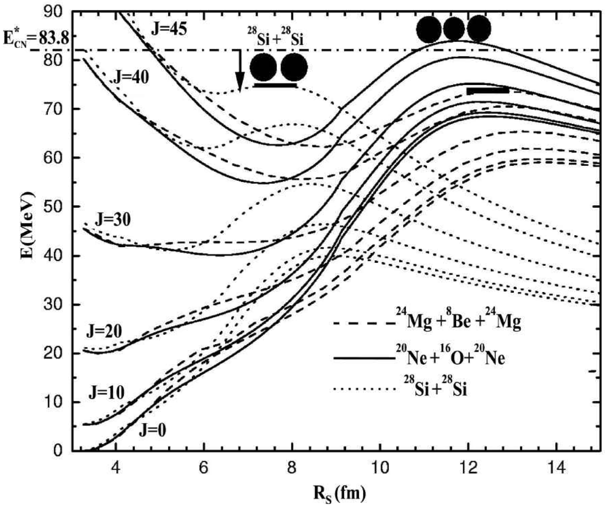
The temperatures reached are only one tenth of those needed for ignition of fusion capsules with only 300 Joules of energy on target. The team found that at least 15% of the laser energy was transferred to the fast electron beam. That transfer fraction informs designs for ignition of fusion targets on the proposed HIPER laser facility. *"Efficient coupling of the laser energy to the target is crucial for fast ignition inertial fusion, and is one of the main questions on which the design of the European laser fusion laboratory, HiPER, depends"*, said Jonathan Davies (Instituto Superior Technico, Lisbon). ■

M. Nakatsutsumi *et al.* (31 authors), "Space and time resolved measurements of the heating of solids to ten million Kelvin by a petawatt laser", *New J. of Phys.* **10**, 043046 (2008)

View of the Vulcan petawatt target chamber with Mr Dan Hey (UC Davis). Scientists are discussing data recorded on the instruments ▶

A possible signature of hyper-deformation from ternary fission

Search for hyper-deformed shapes in atomic nuclei has been challenging nuclear physicists since the discovery of super-deformation by Paul Nolan and Peter Twin in the mid-eighties. For such exotic configurations nuclei are approximated by ellipsoidal shapes with major-to-minor axis ratios of 2:1 and 3:1 for super- and hyper-deformations, respectively.



▲ **Barrier energies for selected fragmentations in the decay of ^{56}Ni as a function of distance between two heavier fragments. The ternary fission process from the hyper-deformed configuration is expected to be enhanced due to a lowering of its ternary fission barrier by the shell corrections**

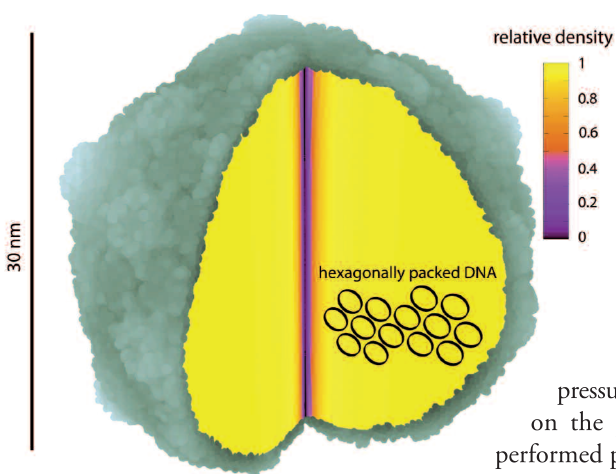
In their recent paper Wolfram von Oertzen and coworkers report on observations of fission and ternary cluster decay events of a high-spin state in ^{56}Ni. This state with angular momentum of about 45 units of ħ was produced in heavy-ion fusion reactions between ^{32}S and ^{24}Mg nuclei at the VIVITRON facility in Strasbourg. Its decay modes were observed by using a highly sophisticated Binary Reaction Spectrometer of the Hahn Meitner Institute Berlin coupled to the EUROBALL Ge-array.

The observed ternary coplanar fission was interpreted to be a signature of the decay of an extremely deformed nucleus at high angular momentum. It is an interesting observation since ^{56}Ni can be considered as spherical doubly magic nucleus in its ground state. For deformed configurations, shell corrections for quadrupole deformation could provide explanations for the observed elongated shape of ^{56}Ni. As suggested by the findings in this paper, measurements of the ternary fission process offer new possibility for a detailed spectroscopy of extremely deformed shapes. ■

W. von Oertzen *et al.* (15 authors), "Fission and Ternary Cluster Decay of Hyper-deformed ^{56}Ni", *Eur. Phys. J. A* **36**, 279 (2008)

From bulk to encapsidated DNA: energetics and density of DNA packed in bacteriophage capsids

The DNA that constitutes the genome of a bacteriophage is tightly packed in a protein shell called a capsid; this shell needs to withstand a large internal pressure from the closely packed DNA. Not much is known about the way the DNA is packed, so we have formulated a new theoretical approach to relate the density distribution of the DNA in the capsid to experimental data connecting osmotic pressure with the DNA density in the bulk. This has enabled us to determine the length of the packed DNA (packing fraction) as a function of the osmotic pressure - this is a quantity directly accessible in experiments. Somewhat surprisingly, we have found that the packing fraction can be reliably calculated even when neglecting the elastic energy of encapsidated DNA, which suggests that these experiments essentially probe the properties of the bulk DNA. Nevertheless, the elasticity of the DNA was found to influence the density distribution of the encapsidated DNA, inducing a very narrow cylindrical core that is depleted of DNA in an otherwise almost uniformly filled capsid. The radius of the depleted core (~1 nm) is small on the scale of the bacteriophage radius (~30 nm) and it diminishes with the increase of osmotic pressure. It has negligible influence on the packing fraction. We have performed packing fraction calculations for bathing solutions of different salts and concentrations. Our results, especially the predictions for $MnCl_2$ bathing solutions, should be easily tested in experiments. ■



▲ **General feature of our solution for the packed DNA density is the depleted narrow cylindrical core (black and magenta) in otherwise uniform distribution of hexagonally packed DNA (yellow). The protein shell (capsid) of a model bacteriophage virus is indicated in green.**

A. Šiber, **M. Dragar**, **V.A. Parsegian** and **R. Podgornik**, "Packing nano-mechanics of viral genomes", *Eur. Phys.J. E* **26**, 317 (2008)

[PHYSICS IN SPACE]

BUBBLES, DROPS, FILMS: TRANSFERRING HEAT IN SPACE

DOI 10.1051/epn:2008401

G.P. Celata [1], C. Colin [2], P. Colinet [3], P. Di Marco [4], T. Gambaryan-Roisman [5], O. Kabov [3], O. Kyriopoulos [5], P. Stephan [5], L. Tadrist [6] and C. Tropea [5]
[1] ENEA Roma, [2] IMF Toulouse, [3] UL Brussels, [4] UNI Pisa, [5] TU Darmstadt, [6] IUSTI Marseille

Phase-change phenomena play an important role in our daily life. They are of great interest for cooling electronic components or engines. They are also used in vapour generators. At least two thirds of the electrical energy produced in the world uses this technique. Two-phase flows are also present in space applications: energy production, electronic cooling devices and, as one can expect in the future, in waste water treatment and life support systems for long-duration space exploration missions. So, in many applications high heat fluxes are achieved by utilising the latent heat associated with the phase change from liquid to vapour. However, the physical mechanisms involved are intricate and many questions remain unanswered: how does a bubble nucleate on a heated surface? When will bubbles completely cover a hot surface? What is the amount of heat transferred by boiling evaporation or reversely, by condensation?

The field clearly is at the crossroads of thermodynamics, fluid dynamics, materials sciences and physical chemistry of interfaces. Because of the complexity of the coupling effects in systems involving phase change and the lack of reliable prediction capabilities, the development of industrial devices is essentially based on empirical rules. Their utilisation then relies on correlations established between operational parameters and heat transfer performances, which cover a limited range of parameters and thus cannot be extrapolated to other situations and in particular to a microgravity environment.

Progress in the field requires a better understanding of the basic mechanisms and the development of predictive capabilities. This is supported by recent advances in measurement techniques and an increase in computing performances. It is however still difficult, if not impossible to discriminate between these individual basic phenomena.

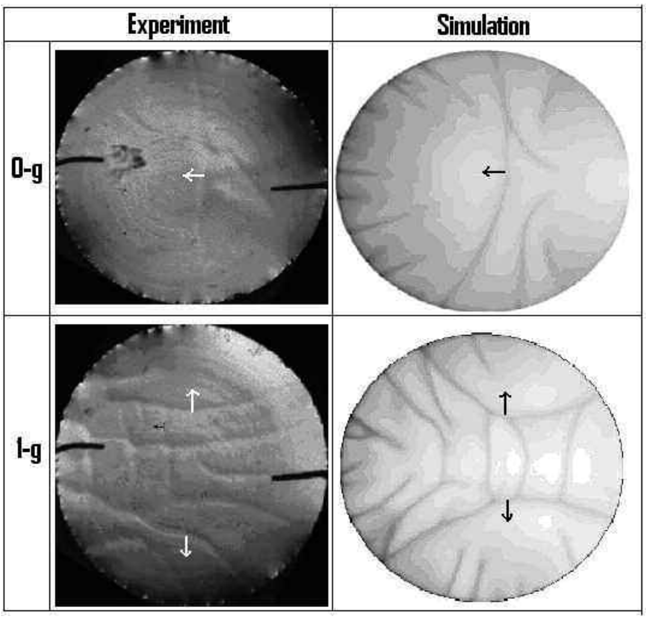
Phase change occurs at interfaces, the boundaries separating different phases. Although molecularly thin, liquid-gas interfaces play a major role in the overall behaviour of the system. It is therefore crucial to understand the details of their static and dynamic behaviour. Because of the principle of minimal surface energy, an interface ideally tends to assume a spherical shape. However, on Earth, the gradient of hydrostatic pressure leads to the flattening of drops and elongation of bubbles. In a flow, viscous and inertia effects are also responsible for pressure gradients and thereby, for interface deformation. In liquid-vapour flows, the density difference is very high and gravity effects dominate capillary and viscous effects. Gravity generates thermal convection and causes bubble detachment during boiling and stabilises liquid films. Under normal gravity it is thus impossible to separate the various mechanisms involved.

Microgravity is a good tool to improve the quantitative understanding of these physical mechanisms. Experiments have been performed in free-fall conditions at different time scales demonstrating the relevance of two-phase flow studies in space. Several instruments have been defined in the frame of international programmes and planned for the International Space Station in order to extend these investigations.

Three different configurations employed for heat transfer are discussed here: evaporation and condensation of liquid films, pool and convective boiling, and spray cooling.

Liquid films with evaporation and condensation

When a liquid evaporates non-uniformly in the air, temperature gradients form along the interface, resulting in a varying value of the surface tension along the interface. This induces thermocapillary flow, known as the Marangoni effect. Even when evaporating uniformly, a liquid layer does not remain quiescent but is subject to hydrodynamic instabilities [1] generating intense motions. On Earth, these motions cannot be clearly dissociated from buoyancy convection due to density variations associated with thermal expansion. Experiments on sounding rockets however [2], have already confirmed the predicted occurrence of convection patterns in evaporating liquid layers (see Figure 1). More detailed investigations of these patterns over a wider range of parameters are already planned to be performed on the ISS.



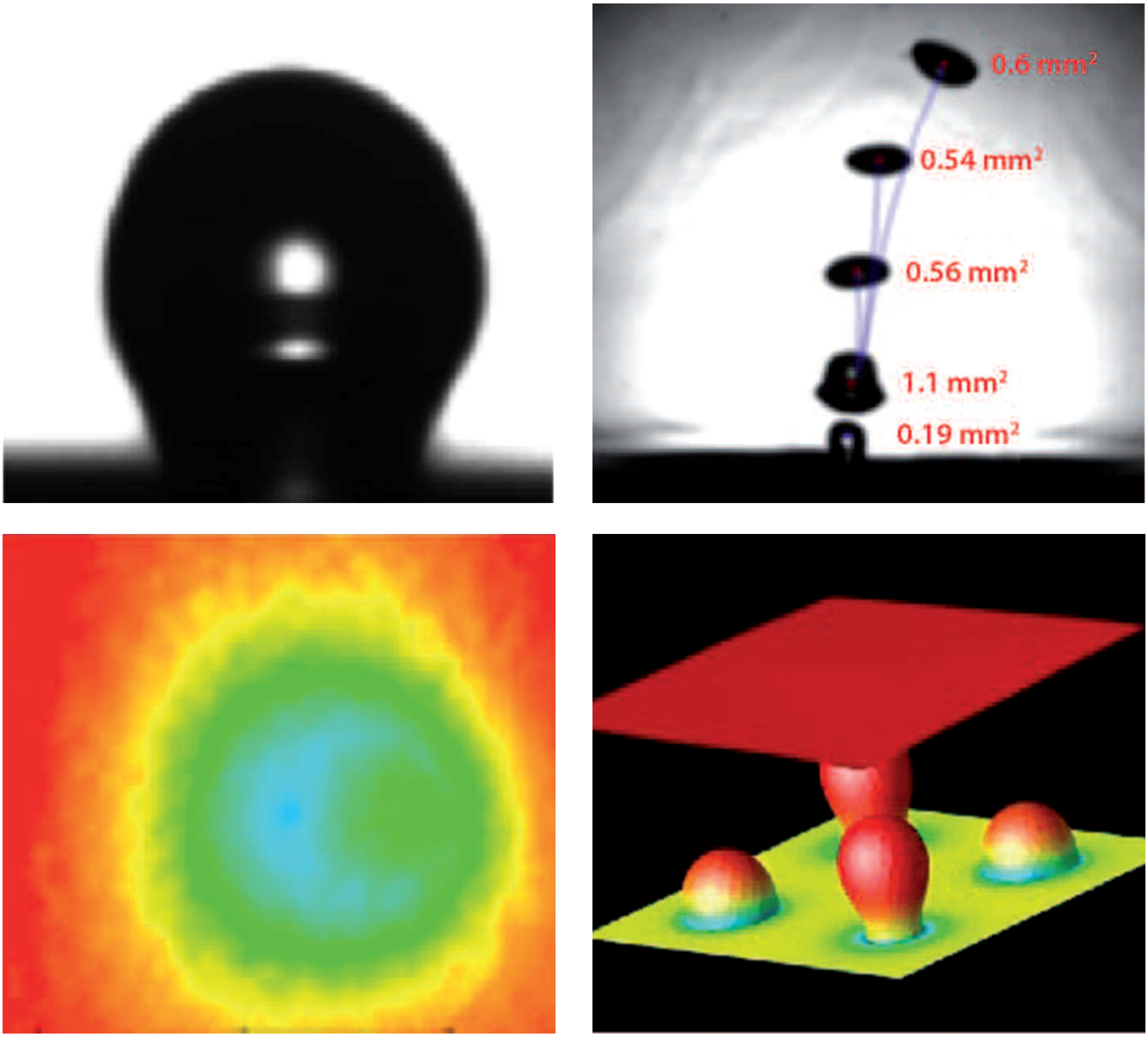
▲ **FIG. 1:** Convective patterns in an evaporating 5 mm layer of ethyl alcohol above which a flow of dry nitrogen gas is established from left to right at a rate of about 330 ml/min. The pressure is about 650 mbar. The snapshots show ripples moving at the interface either upstream in microgravity (0g) or laterally in ground conditions (1g), as indicated by the arrows.

Furthermore, thermocapillary effects may also induce the rupture of thin liquid films evaporating on a hot substrate or flowing along it, *e.g.* in the gravity field [3]. As the temperature of the fluid increases, its surface tension decreases and the resulting surface tension gradient produces a flow opposed to the gravitationally driven flow. This results in a liquid bump in the region of the upper edge of the heating element. Beyond a critical heat flux, rivulets (small 'rivers') start to form at the bump position. They are aligned with the flow and distribute spanwise with a fixed wavelength. If in addition a gas is blown along the liquid-gas interface, waves form parallel to the stream, but with a much smaller wavelength. Under free-fall conditions, surface tension effects dominate such that a liquid film in a horizontal channel becomes a flattened rivulet.

Similarly, the vapour condensation on a cold surface results in either a wetting film or droplets; both gravity and surface tension effects contribute to controlling the flow even if structured surfaces are used as in industrial devices. Condensation is therefore also a subject for future space experiments [4].

Pool and convective boiling

Nucleate boiling occurs when a liquid is in contact with a surface maintained at a temperature above the saturation temperature. Vapour bubbles then nucleate, grow and detach from the heated wall under the effect of gravity and/or liquid flow entrainment (convective boiling). The design of new processes and evaporators is significantly hindered by the fact that general computational techniques and analytical methods are not yet



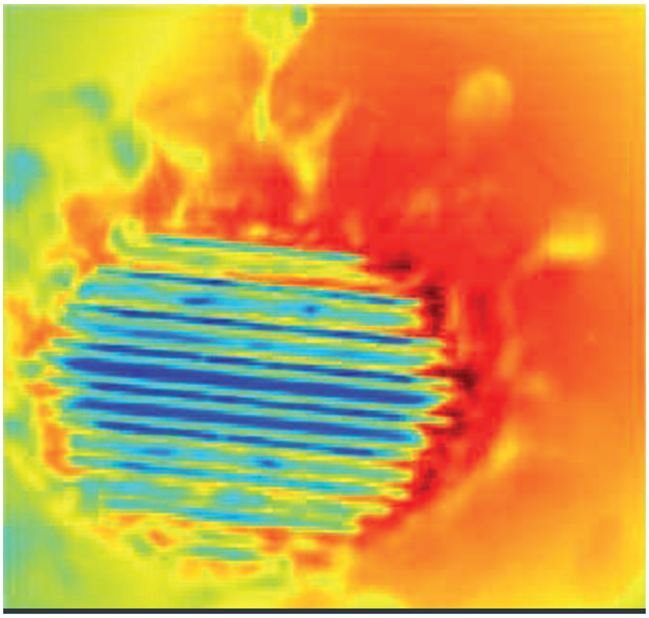
▲ **FIG. 2:** **Simultaneous sideway observation of a single vapour bubble at an artificial nucleation site in microgravity (top left) and vertical observation from below of the heating wall that is covered with a layer of temperature sensitive liquid crystals (bottom left). Bubble detachment in normal gravity (top right). Direct Numerical simulations of bubble growth on a heated plate (bottom right) also in normal gravity (www-trio-u.cea.fr - in french)** available. The existing correlations between the parameters (*e.g.* fluid properties, heater geometry, gravity) and the system performances lack physical contents.

Several European research teams have joined efforts to improve the quantitative knowledge of nucleate boiling. The most sophisticated models for the prediction of the wall heat transfer can include details at the level of single bubbles. Therefore, models of the thermodynamic and hydrodynamic phenomena at different scales have to be developed and experimentally verified by a wide scanning of the parameter space. Vapour bubbles grow from microscopic surface cavities, so called nucleation sites, at the heated wall. The very tiny zone where the vapour inside the bubble and the surrounding liquid meet the heated wall is of significant importance for the heat transfer. Near this three-phase contact area, which is about one-micron wide, the evaporation rate is extremely high and induces a strong local cooling of the heated wall (Figure 2, bottom left panel). This observation was confirmed during microgravity experiments: indeed, in the absence of buoyancy, the growth rate of the vapour bubbles is slowed down and their detachment is delayed, which enables measurements at higher spatial and temporal resolutions [6]. Such high local evaporation rates can now be predicted by advanced models of transient nucleate boiling. These models can in turn be used as sub-grid models at the contact line in advanced numerical methods for the computation of the growth of several bubbles on a heated wall (Figure 2). Additionally, the hydrodynamic effects of a liquid shear flow [5,7,8] and the effect of an electric field upon the bubble to compensate for the absence of buoyancy [9] are also investigated in normal and microgravity conditions.

Spray cooling

A spray impacting onto a rigid wall creates an oscillating liquid film on its surface which is then completely or partially covered. The flows produced by the spray impact can take a variety of patterns such as jets, sheets, crowns and capillary waves [10]. In many cases the free liquid sheets are unstable and break up into secondary drops. The inertia of the impacting droplets is the main cause for the near-wall two-phase flow. In addition, the flow morphology is determined by gravity, by the surface tension and the wetting behaviour of the liquid, by the geometry of the wall and by the phase change. The most prominent effect of phase change can be observed when the wall surface temperature exceeds a critical temperature called Leidenfrost temperature. In this case the impacting liquid droplets remain separated from the surface by a thin vapour film. They evaporate partially or completely without direct contact with the hot wall.

Below the Leidenfrost temperature, each impacting droplet of cold liquid contributes to the cooling of the hot wall surface. The heated liquid then flows away because of the combined effects of inertia and gravity. In reduced gravity the removal of the hot liquid from the surface is slower than in terrestrial conditions. This results in an increase of the liquid film thickness and a reduction of the cooling performance [11]. Consequently, it also reduces the film evaporation rate, which is an important cooling mechanism if the wall temperature is close to or exceeds the saturation temperature.



▲ FIG. 3: Infrared image of a single drop impacting onto a heated liquid film on a grooved wall. The grooved wall surfaces are used for heat transfer improvement. The drop impact created a crater in the liquid film (a large round area with irregular boundaries), which resulted in liquid dry out at the groove crests. The groove troughs are filled with cold liquid of a drop. Secondary droplets produced by the splash are seen around the crater area.

Gravity also has a considerable effect on the near-wall flow [10]. In particular, gravity influences the size of the crater produced by a single drop impact on a liquid film. Gravity affects the film thickness inside the crater and thus, the conditions of the splash (Figure 3). These effects have to be firstly completely understood, measured in microgravity and modelled in order to describe, analyse and ultimately optimise spray cooling on Earth and in space. ■

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[PHYSICS IN SPACE]

FOAMS AND EMULSIONS IN SPACE

››› DOI 10.1051/epn:2008402

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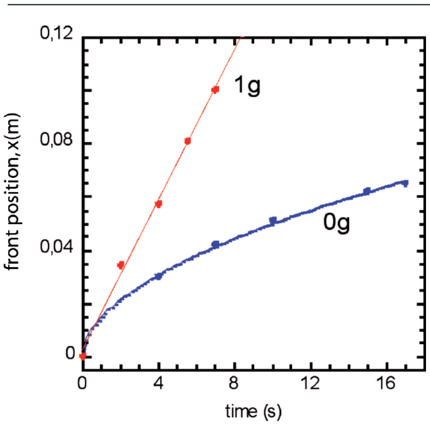
In the physics of fluids, gravity is often an unwelcome intruder because it gives rise to instabilities and inhomogeneities. Microgravity environments such as that of the International Space Station (ISS) offer the opportunity to turn off its unwelcome effects. This strategy is being pursued for the study of three closely related complex fluids: aqueous foams, emulsions, and liquid metallic foams, the latter owing their importance to being the precursor of solid products. Studies of soap or metallic froths and complex emulsions are inherently interdisciplinary as is often the case with condensed and soft matter; interdependent effects take place on three length scales as well as several time scales, each of which requires treatment with appropriate tools:

- *Molecular level* surfactant properties: foam and emulsion chemistry
- *Mesoscopic level* film structure and local behaviour: numerical simulation
- *Macroscopic level* rheology, drainage: hydrodynamic theories

Foams and emulsions are ubiquitous in nature and in industrial products and technologies. Their stability against phase separation is achieved with blends of molecules (surfactants, electrolytes, polymer, protein) which segregate to the interface between the two fluids and hinder droplet or bubble aggregation and coalescence. Seeding with particles also becomes very attractive because of the outstanding stability it provides to the structure of the fluid. Foams and emulsions share common structures and show many physicochemical analogies. They feature liquid films between bubbles or drops and transition zones called the Plateau borders.

European groups have a strong record in this area of research on the ground as well as in microgravity, including both parabolic flights and sounding rocket missions [1-6]. Adsorption dynamics and dilational rheology of surfactants at liquid interfaces were investigated onboard the Space Shuttle, which allowed models adopted for surfactant adsorption to be validated [7], [8]. The younger generation has also been exposed to the delights of foam physics, when undergraduate students earned high commendation for their successful achievement of the extension of one of Plateau's classic wire-frame experiments to the microgravity environment of a parabolic flight [9].



◄ FIG. 1: Position of the liquid front in forced drainage experiments: red circles, on ground, the liquid velocity is constant; blue circles, in 0g: the propagation is diffusive and slower, allowing one to reach much larger volume fractions – instabilities seen on ground are prevented [2].

The structure and properties of foams

Foams are made of closely packed gas bubbles in a liquid, typically water with a surfactant. The liquid volume fraction φ may vary from less than one percent (dry foam) to around 35% (wet foam). When $\varphi > \varphi_c \sim 35\%$, the bubbles are spherical and move freely in a "bubbly liquid". A "jamming" transition takes place at the critical liquid fraction that brings bubbles into contact. Such wet foams are rather inaccessible under gravity, at least in equilibrium (except for very small bubbles). The froth on your beer, if you wait for it to settle, is "dry". The addition of liquid at the top can create steady-state drainage, with a constant volume fraction. This can be used to study wet foams in a steady state but only up to a liquid fraction of about 20%, beyond which various dynamic instabilities (primarily convection) occur – hence the need for microgravity which allows the production of such wet foams (see Fig. 1).

Metallic foams

Metallic foams [10] are of considerable interest for light structures or shock absorption applications. But they can suffer from pronounced drainage in the liquid state under the influence of gravity, unless appropriate measures are taken to prevent fluid flow. The reasons for this drainage lies in the high density of most metals – 2.5 g/cm^3 for liquid aluminium – and a viscosity-to-surface tension ratio which is less than 1/10 of water, combined with the usually high liquid fraction (>10%) in most liquid metal foams. As the films become thinner, they rupture at critical thicknesses around 50 μm, something that must be eliminated to obtain a useful engineering material. This can be done by incorporating solid oxide particles within the films and Plateau borders in order to keep the two interfaces apart and efficiently block flow [11]. This stabilisation technique is largely inspired from the similar effect of powders on emulsions first observed by Pickering.

Foams in microgravity

Microgravity experiments can probe the details of foam *structure* (the shapes and arrangements of bubbles), *conductivity* (which can be related to liquid fraction), coarsening (due to diffusion of gas: growth of large bubbles, shrinkage of small ones), drainage and capillarity (both due to gravity), *rheology* (a foam being a good example of a *complex fluid*, combining liquid-like and solid-like properties) and *bubble coalescence*.

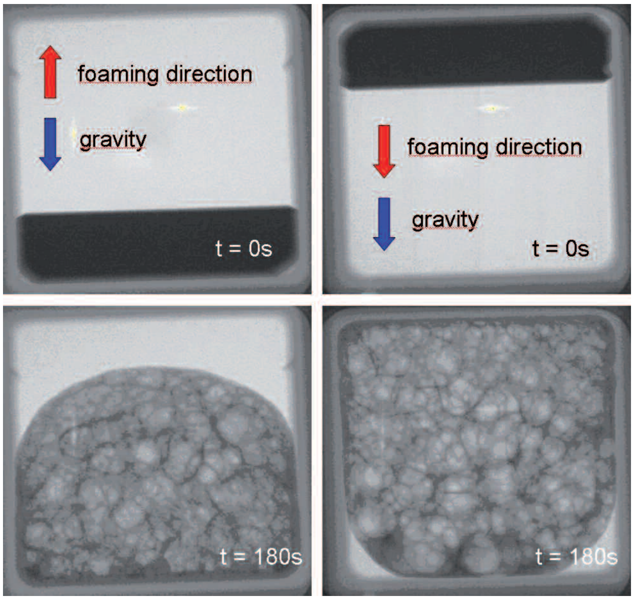
The bubble growth laws (coarsening) must be different in the wet and dry foam limit, but this evolution has never been fully checked. The same difficulty occurs with rheology: how do wet foams flow? So wet foams as well as dynamic effects are still a terra incognita of many fascinating problems. Their eventual solution will provide a scientifically valid alternative to the necessarily conservative empiricism currently used to evaluate the operational window and design for foam handling in many industrial processes.

Objectives within present ISS research programmes include the measurement of all these properties to be measured for aqueous foams in a single instrument. A full set of data on capillary drainage has already been obtained during parabolic flight experiments [2] giving better understanding of the liquid repartition inside the foam at high liquid fractions. First tests are performed in gravity with foams made of solutions containing surfactant and solid particles (such as fumed silica): this is a direction towards which intense terrestrial research is turning, with strong commercial motivation *e.g.* in the food industry.

The interplay between drainage and coalescence in *metallic* foams is obscured by the presence of gravity and it is highly desirable to study rupture without disturbing liquid flows and while holding the liquid fraction at a constant level. However insight into the internal configuration of the foam is necessary in order to quantify both drainage and rupture, which is realizable by X-ray radioscopy, as already used in the laboratory [12]. Integration of such facilities into a microgravity environment is an engineering challenge because of safety aspects and miniaturisation.

Aluminium alloy foam is created inside a small ceramic furnace: with a microfocus X-ray tube and a flat panel detector, one can observe in situ the mass density projection of the growing foam. In the left panel of fig. 2, foam is shown to expand from bottom to top and gravity hinders vertical expansion and causes drainage. In the right panel, gravity helps the foam to expand, but liquid still drains to the bottom. Zero gravity experiments on parabolic flights or on sounding rockets will show how foams evolve without drainage for up to minutes.

In the long run, one should be able to reliably produce homogeneous solid foams on Earth: new scientific findings will enable better materials to be produced for a market which offers many opportunities for cellular metals [12].



▲ **FIG. 2: X-ray radiograph of ground tests of the aluminium foam furnace successfully used in the sounding rocket experiment of April 2008. Various configurations were tested, including foaming against gravity (left panel, "1g") and supported by gravity (right panel, "-1g") and tests were also performed on parabolic flights. All flight data are being analysed.**

Emulsions in microgravity

Applications call for efficient and low cost methods for stabilisation or destabilisation of emulsions. In order to fill the knowledge gap between the present semi-empirical practice and a more deliberate design of emulsifiers, ESA supports a programme involving different European teams from academia and industry, working on terrestrial investigations as well as on microgravity experiments scheduled to take place within the next two years on board Columbus. Research topics range from the adsorption of surface-active components of emulsifiers to the collective behaviour of emulsion droplets as well as the dynamics of the liquid film between droplets. Droplet aggregation and coalescence are mostly conditioned by the physicochemical properties of films where dilational surfactant transport and interfacial rheology - the dynamic interfacial tension response to extensions of the interfacial area - play a key role. Weightlessness entails various simplifications allowing for an accurate measurement of kinetic parameters concerned with surfactant transport, adsorption and interfacial rheology. It also provides for simplified and controlled conditions under which the process of destabilisation of emulsions and specific interactions between droplets can be investigated. The elimination of buoyancy allows an effective study to be made of the processes of droplet coalescence or aggregation, which under terrestrial conditions are strongly coupled with gravity segregation. Experiments are planned that will focus on the dilational rheology of mixed surfactant layers subject to adsorption and to partitioning between the liquid phases.

Further experiments on ISS employing specifically designed diagnostics will address the stability of emulsions formed with surfactants and/or particles [13,14]. The objective of these experiments is the investigation of droplet-size distribution ▸

▲ **FIG. 3:** The future of foam research on the ISS? (courtesy of Wiebke Drenckhan).

evolution during destabilisation, of droplet pair-wise interactions and coalescence, and of the droplet dynamics in order to study regimes driven by capillary flows.

So far, important industrial processes and products have been developed without the benefit of well established science-based models. With the gravity level becoming a variable parameter, scientists in academia and industry are enabled to formulate more tractable models. Today ESA has brought together three scientific communities and related industry whose cooperation makes the future of foam and emulsion research very promising (see Fig. 3). ■

Acknowledgements

The studies summarised here are the result of the active and fruitful collaboration of the different research groups involved in the ESA MAP programmes 'FASES' (Fundamental and Applied Studies in Emulsion Stability, 'Hydrodynamics of Wet Foams', 'µgFOAM' (Advanced Foams in Microgravity), and 'XRMon' (X-Ray Monitoring). We wish to thank all the colleagues participating in these programmes, including in particular Michele Adler, Mickaël Antoni, Anne-Laure Biance, Hervé Caps, Danielle Clausse, Sylvie Cohen-Addad, Reinhard Hoehler, Giuseppe Loglio, Olivier Pitois, Annie Steinchen, Nicolas Vandewalle, as well as Douglas Durian of the NASA foam project.

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[PHYSICS IN SPACE]

GRANULAR MATTER UNDER MICROGRAVITY

››› DOI 10.1051/epn:2008403

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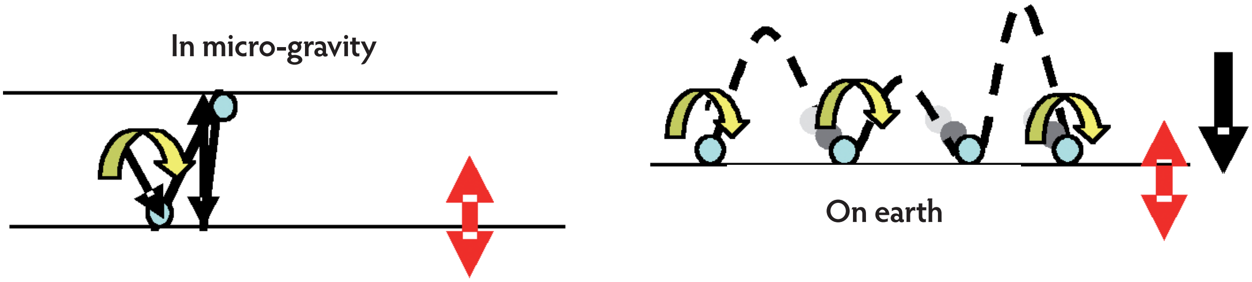
The physics of granular matter under microgravity conditions is important for different fields, ranging from very technological issues such as the management of grains and powders in space, to very fundamental problems like the formation of asteroids or the history of Earth formation. However, in the physics of strongly dissipative systems such as a granular gas, we do not even know if a collection of grains excited by some steady source of energy reaches a steady state or not, and whether the state is unique. Of course, it would be convenient if one could extend the usual thermodynamic concepts of gases and liquids to this kind of matter, then defining under which conditions, with which transfers between the two parts of the system, on which time scale such an extension would be valid.

Here, we consider the problems encountered with granular matter in space and the most realistic way of addressing them by using controlled vibrations to perturb the grain system.

Granular gas excited by vibration

A question of current interest is: what are the basic properties of granular matter under vibration and weightlessness conditions. The experimental situation is a simple parallelepipedic cell containing a fixed number of grains and the cell walls subjected to harmonic vibrations (frequency f, amplitude A). The grains are then excited by the vibrating cell walls. They can move "randomly" and dissipate energy during grain-grain collisions.



▲ **FIG. 1:** Without gravity (left panel) the rotational energy of the spherical grain is progressively dissipated. Clockwise rotation is induced by the first impact. Upon the second impact, the opposite wall induces a counter clockwise effect. Because of the dissipation of energy on impact, there is only a partial restitution of the rotational energy. The motion eventually becomes 1-D stabilised. On Earth (right panel), if vibrations (red arrows) are applied vertically, gravity (black arrow) is left to play the role of the ceiling wall. Alternating conditions on rotation do not apply and the motion of the grain is not stabilised.

A number of questions then arise: What is the behaviour of each grain? Does a steady state exist for the grain collection? Does the grain system look like a gas, a liquid, a solid? How does it scale with the cell size or the number of particles? Can one observe some kind of gas-liquid or gas-solid transition? What is the distribution of grain velocities? Does the vibrating cell play the role of a thermostat?

We illustrate the subtle complexity of these problems with some examples described in terms of the cell filling ratio. It turns out that when the cell is excited along its longest wall of length L, the main physical parameter is the number n of layers of grains contained in the cell at rest on Earth. Indeed, $L/n \approx l_c$ scales as the mean free path l_c between grain-grain collisions.

Consider a single spherical grain in a three-dimensional (3-D) cubic box where there is obviously no grain-grain interaction.

In the experiment in weightless conditions, at small vibration amplitude A, the grain speed is quite small (and erratic) in the direction perpendicular to vibration, while it is much larger but erratic from one bounce to the next along the vibration direction.

However, we have observed that the motion of the sphere becomes essentially periodic (with some intermittency) once the vibration amplitude exceeds a threshold. This threshold is related to the normal restitution coefficient, that is the ratio of the grain velocities after and before the bounce and is different from one. As the grain moves linearly along a single direction, it makes a round trip within a vibration period, such that its speed is much larger than that of the vibrating cell (*i.e.* $Lf >> \pi A f$).

In this microgravity experiment, alternate bouncing freezes the grain rotations and motions in the other directions, as illustrated in Figure 1. A finite friction coefficient between particle and wall imposes that a grain with an inclined trajectory rebounds with some rotation on the first surface and with a counter-rotation on the second surface; this process enhances considerably the energy losses and finally freezes the rotational degrees of freedom. A comparison with bouncing on Earth is illustrated on the right panel of Figure 1.

Single grain problem: A simple case?

A grain moving in a 3-D vibrating box, with two parallel walls oriented perpendicular to the periodic vibrations, is controlled by 13 independent degrees of freedom: 1-time (for vibration), 3-position- and 3-rotation- coordinates plus 3-translation and 3-rotation speed coordinates. So this is a very complex system similar to the dissipative billiard, except that, when the periodic dynamics exceeds some threshold, it becomes a simple system whose main average position and speed can be predicted.

Of course, the dynamics becomes more complicated if the grain is not perfectly spherical, if the walls are not perfectly flat, or if opposite walls form a tilted-angle. In addition, we understand that when the grain speed v_g is large compared to $2\pi A f$ (or when the restitution coefficient approaches one in numerical simulations), it can randomly collide with the moving wall when the wall goes back or forth. Then, at each bounce, the grain can decrease or increase randomly its speed and the periodic solution looses stability.

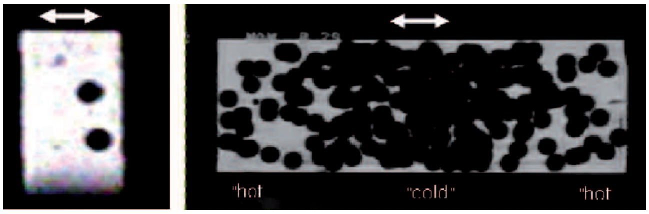
Increasing the complexity

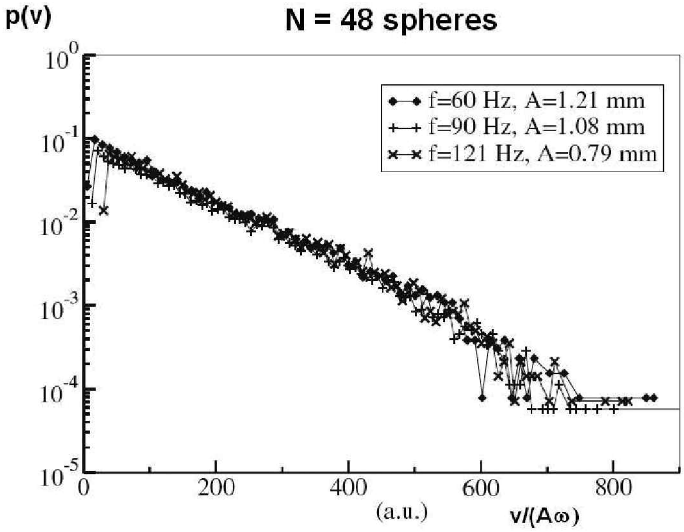
If one performs the experiment with two grains of the same size, both move at the same speed when the motion is periodic (see Fig. 2). When the number of grains is further increased, they start interacting strongly, repelling each other by collision. Their motion then becomes erratic.

The grain dynamics then varies with the number of particle layers n:

- If the number of grains is small (*i.e.,* n<1.5 layers), the trajectories look ergodic, which means that on average, the motions of the grains all look similar with the same statistical distribution in space and speed, but there is no long-term correlation.

▼ **FIG. 2:** Left panel: Snapshot of two grains moving at the same speed in a vibrated cell under weightness conditions (the direction of vibration is indicated by the white double arrow). Both particles collide only with the walls and make a round-trip per vibration period. Their speed is then much larger than the wall speed and their motion remains "coherent", that is, in phase with the vibration. Right panel: Many grains that collide with the walls and with each other. The grain density is higher in the middle of the cell, and correspondingly the local temperature is lower (vibration amplitude A= 0.3 mm and frequency f=60Hz. Experiments on Maxus [5] sounding rockets).





▲ **FIG. 3: The probability distribution function p(v) of impacts at speed v on a fixed plane was measured in a cell containing from 0.5 to 1.5 layers of spherical grains excited by the sinusoidal motion of a piston, with variable frequency f and amplitude A. This distribution p(v) follows an exponential law exp(-v/v$_o$) with v$_o$ varying linearly as a function of the maximum boundary speed Aω=2πAf. As the distribution f(v) of speed in the cell is related to p(v) by p(v)= v f(v), f(v) varies as (1/v) exp(-v/v$_o$). As a result, the number of grains with low speed is larger than the equilibrium Boltzmann distribution in a gas f(v)= exp(-v^2/v^2_o) . The data shown are for a 48-grains case, *i.e.* 1.5 layers. The exponential decay is found to vary with the number of grains N: the typical impact speed <v> decreases as N is increased; it's value <v> is <v>≈ Aω for N=0.5 layer.**

This low number of particles fills uniformly most of the available space, except for the zones covered by the moving walls. However, this system is not completely random and the speed distribution is different in 3-D and 2-D cells. We also found (see Fig. 3) that fast grains exhibit a speed distribution $f(v) = (1/v)\ exp(-v/v_o)$, which is different from the Boltzmann-Gibbs equilibrium distribution $f_B(v) = exp(-v^2/v_0^2)$. This result should not be too surprising since an excited granular system is a non-equilibrium system. However, in most theoretical approaches the equilibrium approximation was used before these results were presented. The non-Boltzmanian distribution should be due to the significant effect of the grain-wall collisions which increase the number of grains with low and large velocities as compared with classical gas particle velocity distribution.

• For systems with larger numbers of grains corresponding to between 1.5 to 3 layers, an in-homogeneous gas is observed. Grains do not have the same kinetic energy (temperature) everywhere; they are slower in the middle of the cell and faster at the boundaries (where the kinetic temperature is higher). In this range of concentration, the particles always have a speed smaller than the boundary velocity. In a granular gas, we note that the information propagates from grain to grain through grain-grain collisions. Hence the speed of sound is typically related to the mean speed of grains. As it is lower than the speed of the walls, the excitation then becomes "supersonic" (but so far, neither compression nor shock waves have been detected).

Many new insights were gained from these experiments, especially the main role of energy losses due to the rotation of the grains. As firstly pointed out in the unexpected 1-ball coherent behaviour, freezing rotation selects and stabilises the linear trajectory of the ball. But when the number of grains is large, rotation effects are dominant in grain-grain collisions. Since these are not frontal collisions, some degrees of freedom get frozen during collisions and energy losses increase. However, how this increase of energy loss can be taken into account in modelling and numerical simulations remains unknown. For example, the speed distribution presented in figure 3, which was measured at low grain density, could not be reproduced by simulations using the normal restitution coefficient.

At rather high grain density, dynamic clustering or phase separation can be observed in such simulations, often starting with a uniform cloud and a given Boltzmann speed distribution. The present investigations show that such initial conditions are rather unrealistic, or at least difficult to create experimentally. These results trigger quite a number of questions. Should a "mean" restitution coefficient or some other parameters and mechanisms be considered? Can the $f(v) = (1/v)\ exp(-v/v_o)$ distribution be considered as a precursor of the clustering or the intermixed phases? How does it lead to phase separation, if it occurs, when the number of grains is increased?

The need for long duration experiments with high quality microgravity

A large spectrum of experiments should be undertaken to explore the whole parameters space. These include in particular the vibration parameters (A, f), the number, the size and the material of grains and the cell dimensions. High quality weightlessness is required as soon as the number of grain layers exceeds 2 or 3, otherwise g-jitters can prevent a steady-state to be reached or maintained (as was already observed during parabolic flights). For the immediate future, a number of problems have been selected. These are concerned with the dynamical behaviour in two-dimensional samples, the onset of convection in dense samples, the segregation process in two-species materials, the characterisation of the impact of grains on a plate and of a large number of balls on a packed granular system. These experiments would give at least some clues to some of the important problems encountered in the study of granular materials. ■

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▲ **FIG. 1:** The IBM 305 RAMAC data processing computer, introduced in 1956, featured the world's first disk storage unit (IBM 350). Photo courtesy IBM.

CAN DATA BE STORED IN A SINGLE MAGNETIC ATOM?

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In 1956, IBM introduced the 305 RAMAC data processing computer. The machine, shown in Fig. 1, was so big that it had to be delivered by cargo airplane. Its hard disk unit consisted of fifty 24" disks and had a total capacity of almost 5 megabytes. Compared to today's I-Pods and USB flash drives, which can store multiple gigabytes and are yet small enough to be accidentally left inside a pocket when doing the laundry, the kitchen-sized RAMAC makes a rather outdated and even comical impression. But that's really just an impression: technologically, the hard disk that is currently inside your laptop is almost exactly the same – only much smaller.

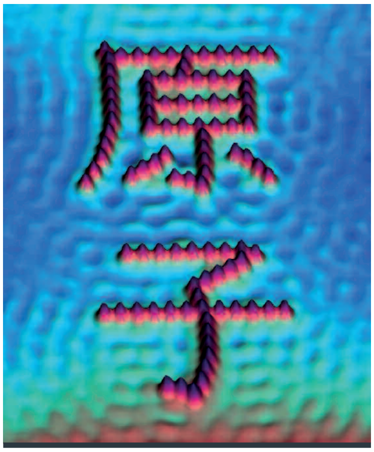
Unfortunately, the ongoing miniaturization of magnetic data storage as we know it (and inherently, the increase of the capacity) is soon coming to an end. That is because by reducing the size of the magnetic domains on the disk, we inadvertently also decrease the magnetic stability of these domains. Just how abrupt this ending will be is illustrated very well by the following example [1]. Take a magnetic domain that is just large enough to be stable, meaning that it can maintain its magnetization direction (*i.e.*, the data) for, say, 10,000 years at room temperature. Now reduce the volume of this domain by only a factor of two: as a result of this seemingly small change, the magnetic decay time will suddenly drop by more than ten orders of magnitude to mere seconds! This merciless property of nature is known as the *superparamagnetic limit*.

Exactly at what domain size the superparamagnetic limit will take its toll depends on the type of magnetic material used. Or more precisely: it depends on how anisotropic that material is. For it is that property, magnetic anisotropy, that determines how well the domain's magnetic moment can tell one direction from the other. The more it prefers one specific axis to magnetize along, the less likely it is that the magnetic moment will swivel off in some random direction and thus erase the data it is supposed to represent. Therefore, control of the magnetic anisotropy of a material is the key towards stretching the limits of conventional magnetic data storage.

Nonetheless, the end of this process is near and will be here sooner than we would like. Therefore, rather than discussing incremental improvements, we will now consider a bold solution. Maybe even the boldest of all solutions: to make an individual magnetic atom hold a single bit of data. Seeing that the smallest bits currently available cover an area that can still host tens of thousands of atoms, this would be a stunning leap forward. Could it be done? Well, that depends on various things. First of all, it depends on what we mean by a 'magnetic atom'.

Magnetism of an atom

Magnetism is carried by the electrons on an atom. More specifically, it is carried by their intrinsic magnetic moment (*spin*), by their orbital angular momentum, or a by a combination of the two. In many cases the total amount of either quantity is zero. This is most notably the case when there are no partly filled ►



▲ **FIG. 2:** STM image of iron atoms on a Cu(111) surface. The atoms are arranged to form the Kanji characters for "atom". Image courtesy IBM.

▸ electronic shells on the atom, but happens also if a net amount of magnetic moment is 'consumed', for instance in forming a molecular bond with another atom. In each of these cases the atom is certainly not magnetic. But is the opposite also true? Is an atom that does have an uncompensated magnetic moment (such as an iron, cobalt, manganese or nickel atom) automatically magnetic? No, there is slightly more to it than just that.

Here we return to the anisotropy requirement mentioned above, which holds for individual atoms as well. A free atom suspended in space can never exhibit magnetism, regardless of its electronic configuration. If all directions are equivalent, it simply does not know which direction to magnetize in. So in order to make an atom magnetic, we need to place it in an anisotropic environment (for example, a solid state material). And that's exactly the idea of experiments recently published by Hirjibehedin *et al.* [2], which are described below: take a single atom with an uncompensated magnetic moment, place it onto an anisotropic surface and figure out (1) what direction it likes to magnetize in and (2) how badly it wants to point in that direction (*i.e.*, how much effort it takes to make it point elsewhere).

Seeing atoms and moving them around

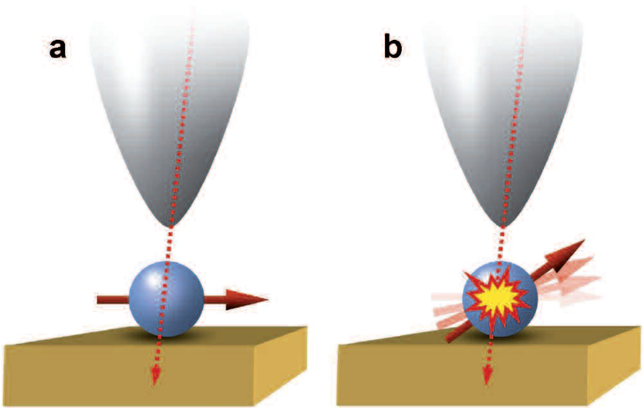
Maybe we should take a few steps back here. Because before we can even come close to putting an individual atom anywhere, we first need to be able to see it. This is where the Scanning Tunneling Microscope (STM) comes in, a device in which an atomically sharp needle (tip) scans along a surface in a manner strongly resembling a record player. While imaging, the STM tip does not contact the surface. Instead, it hangs a few tenths of a nanometer above the surface and maintains that separation by keeping the current of electrons tunneling through the vacuum gap between tip and surface constant. (For an introduction into the principles of STM, see ref. [3].) This way, when the tip scans over an atom that lies on top of the surface, its height temporarily increases such that the atom appears as a small bump.

But the STM can do much more than just imaging. Having seen the atoms, it can in some cases also move them around to any desired spot on the surface. In order to do so, the STM tip is lowered until it touches the atom, after which the atom can either be dragged along by the tip, or even be picked up and dropped off somewhere else. With this principle, first demonstrated in 1990 [4], increasingly complex structures (such as the Kanji characters shown in Fig. 2) can be built on an incredibly small scale. This technology has its limitations though: in order for the atoms to stay put on their designated spot, temperature needs to be reduced to no more than a few Kelvins. Additionally, such atomic scale construction works should be performed in an ultra-clean vacuum environment as to prevent contamination by unwanted gas molecules.

Spin excitation spectroscopy

With this atom manipulation technique the first part of the single-atom-magnetism experiment is taken care of: we can pick up an atom and put it anywhere we want. Unfortunately, the second part is bound to be even more challenging: how do we figure out its magnetization state? Even for a macroscopic everyday magnet, finding the magnetization direction can be challenging. Most people would intuitively use the following method: first they would let the magnet relax into its preferred state (for instance stuck on top of another magnet) and then they would take it out of this state (rotate it, or pull it slightly off the magnet) while mentally recording how much effort each of these 'excitations' takes. After only a few such tests one can form a mental image of both the direction and the strength of the magnet's field. A very similar analysis can be performed on atomic spins, but there's one big difference: since atomic spins obey the laws of quantum mechanics, only a discrete set of well-defined excitations can be made to it. As it turns out, this property is highly useful for obtaining a detailed quantitative insight into the spin's behaviour.

The technique that was used to do this analysis is called *Spin Excitation Spectroscopy*. This technique consists of placing the STM tip over the magnetic atom of interest and slowly increasing the voltage applied between tip and surface. At low voltages little will happen: the atom's magnetic moment will point in its preferred (ground state) direction and tunneling electrons will peacefully pass through the atom on their way from the tip to the surface (Fig. 3a). But from a certain threshold voltage onward, the tunneling electrons injected into the



▲ **FIG. 3:** Above the threshold voltage electrons can tunnel through the magnetic atom either elastically **(a)** or inelastically **(b)**. In the second case a spin excitation is made and the electron loses energy. Below the threshold voltage only elastic tunneling **(a)** is allowed.

atom will have sufficient energy to perform an allowed excitation of the spin (thus losing some of their energy), and still have enough energy left to complete their journey into the surface. In this situation electrons can contribute to the tunneling current in two ways: either elastically by leaving the spin unchanged, or inelastically (Fig. 3b) by performing an excitation on the spin. As a consequence of this second tunneling possibility, the electrical conductance through the atom will show a sudden increase at the threshold voltage, telling us precisely the energy involved in the excitation.

In the experiments described in ref. [2], spin excitation spectroscopy measurements were performed on magnetic atoms lying on top of thin islands of copper-nitride (Cu_2N) that were grown on one of the facets of a copper crystal. These one atom-layer thick islands, which can be seen quite nicely in Fig. 4a, serve two purposes. First, they separate the atomic spins from the underlying metal, which is necessary for a clear definition of the spin's energy levels: by decoupling the localized spins from the free electrons in the metal the relaxation time of the spin increases as a result of which the levels become sharper.

But more importantly, the surface of these islands provides a strongly anisotropic environment that is ideal for the purpose of the experiment. Obviously, if an atom is placed onto any surface, the direction normal to the surface will always become unique. But if an atom is placed onto one of the copper atoms in the Cu_2N layer as shown in Fig. 4b, there is a clear distinction between the two in-plane directions as well. In one direction the atom is neighboured by two nitrogen atoms (the "N-direction"), while in the other direction it has two hollow sites as neighbours ("hollow direction"). This anisotropic situation was found to impose a distinct directionality on the spins of both manganese and iron atoms. For now, we will limit ourselves to the results obtained on an individual iron atom.

Exciting results

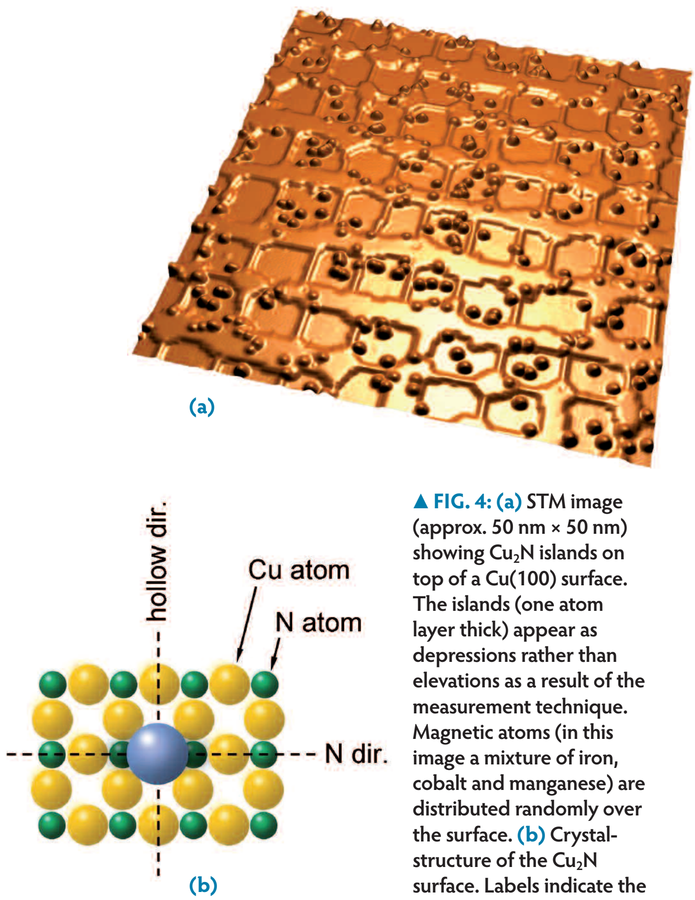
Figure 5 shows a measurement of the conductance (more precisely, the *differential* conductance, the derivative of the current to the voltage) through a single iron atom as a function of the voltage applied over the atom. The graph is almost symmetric, as it should be: the only difference between positive voltage and negative voltage is the direction of the flow of electrons, which should in principle not be relevant for performing spin excitations.

On either side the graph shows three distinct upward steps in conductance: one at less than 1 mV (labelled red), one around 4 mV (green) and one around 6 mV (blue). Each one of these is a direct observation of an inelastic spin excitation performed by the tunneling electrons as discussed above. This is a fantastic result: it directly demonstrates that the iron atom has indeed found a preferential magnetization direction. Otherwise, if all directions would have the same energy, no finite-energy excitation would be possible and the conductance measurement would show a flat line.

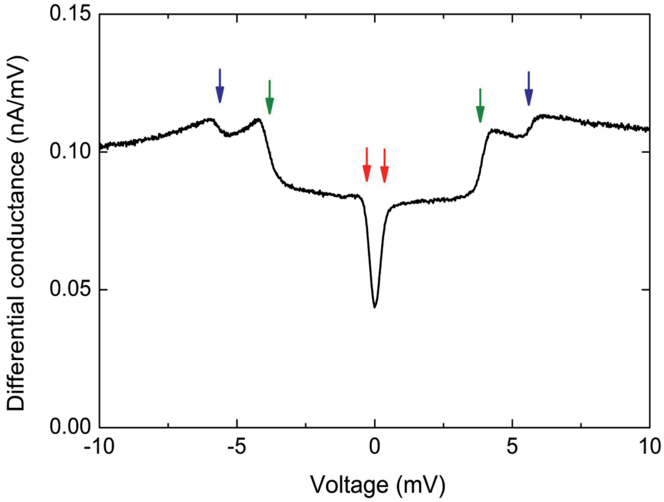
But we are not quite there yet, because these steps do not tell us which direction this preferred direction is, or what kind of excitations we are making. In order to find that out as well, strong magnetic fields were applied along the primary axes of the Cu_2N crystal surface. The idea of this method is that by seeing how the excitation energies change as a result of these fields, it might be possible to get an idea as to which step corresponds to which excitation of the spin. This idea turns out to work very well.

To start, let us see what happens to the iron atom's spin if a 5 Tesla magnetic field is applied along the N direction (Fig. 6a). For now we will focus on the 'blue' excitation (the one that used to be around 6 mV): it has gone up in energy and occurs now at least 1 mV higher in voltage. This means that we still don't know what kind of excitation it is, but that whatever it is, it becomes *harder* to do it when the field points in the N direction. Next, we apply the same size magnetic field over the atom along the hollow direction (Fig. 6b): in contrast, now the blue step clearly goes down in energy. So whatever it is, it surely becomes *easier* to do with the field oriented like this.

With that we have found just enough clues to form ourselves a 'mental image' of the spin's orientation. An explanation that fits both observations is that the iron spin prefers to point in the N direction, and that it takes a tunneling voltage of about 6 mV (corresponding to an electron energy of 6 meV) to turn it away from that direction in the plane of the surface. If we apply a magnetic field along that preferential direction, the spin gets pinned ►



▲ FIG. 4: (a) STM image (approx. 50 nm × 50 nm) showing Cu_2N islands on top of a Cu(100) surface. The islands (one atom layer thick) appear as depressions rather than elevations as a result of the measurement technique. Magnetic atoms (in this image a mixture of iron, cobalt and manganese) are distributed randomly over the surface. **(b)** Crystal-structure of the Cu_2N surface. Labels indicate the hollow and N-directions for an iron atom bound atop a copper atom.



▲ **FIG. 5: Spin Excitation Spectrum measured on a single iron atom. Steps occurring at finite energies indicate that the atom has magnetized.**

▸ down even stronger such that the rotation energy increases. But if we apply the magnetic field along the hollow direction, we 'help' the spin to rotate away: it all makes perfect sense.

A more involved analysis of the results has shown that this is indeed the case. The iron atom's magnetic moment behaves as a spin-2 system of which the ground state has full magnetization along the N direction (*i.e.* $|m_N| = 2$). The blue excitation puts the spin into an $|m_N| = 1$ state, with the majority of the remaining magnetization pointing in the hollow direction. Similarly, the green excitation (going up in energy in Fig. 6a while staying constant in Fig. 6b) brings the spin to a different $|m_N| = 1$ state: this time by rotating the spin towards the surface's normal axis rather than towards the hollow direction.

Well? Can it hold data or not?

Finally, the low-energy red transition corresponds to a full 180° spin flip. This is the manipulation we would be most interested in from the viewpoint of magnetic data storage: it changes the bit from its '0' state ($m_N = +2$) to its '1' state ($m_N = -2$). At first sight this doesn't look too good: as seen in Fig. 5, only 0.2 meV is needed to perform this flip, making the bit highly unstable. But that's just an illusion: due to the precise quantum mechanical nature of the situation, the '0' and '1' of the bit are not well defined in the absence of a magnetic field. Instead, the spin switches from one superposition of '0' and '1' to the other.

If, however, a magnetic field is applied along the N direction (Fig. 6a), this red transition quickly dies out. Already at 2 Tesla we can speak of clearly separated '0' and '1' states. In this situation, the only way to get from one side to the other is by making an actual rotation; either through the 'blue' path or through the 'green' one. And as we have seen above, these transitions take quite a bit of energy. Using these values one can calculate that an iron atom on Cu_2N could in principle remember its bit of information up to a few years, provided that it is cooled down below a temperature of approximately 2 Kelvin.

So the final answer is: yes, data can be stored in a single magnetic atom. But will atomic hard disks be available in your local store soon? Certainly not. Many technological obstacles still need to be overcome before this principle can be put to practice. First and foremost an atom/substrate combination should be found that provides an even higher energy barrier for the bit, such that it can be used at higher temperatures. It should be noted though, that the 2 K operating temperature mentioned above sounds more dramatic than it is. If a system were to be found that is stable above only 77 K, the temperature of liquid nitrogen, applications in large-scale data centers could already become feasible.

A more serious objection, however, is that we now only know that an atom can hold information. How the information should be written onto it and how it can be retrieved are different issues altogether that require independent investigation. Another complication comes with the fabrication of atomic-scale storage media: while the STM is useful for arranging atoms one at a time, no device is to be expected any time soon that can do the same thing on an industrial scale. At least, probably not soon enough to beat the superparamagnetic limit. ■

About the author

Alexander F. Otte currently works as a Postdoc at the Center for Nanoscale Science and Technology at NIST in Maryland. In early 2008 he received his PhD from Leiden University. His thesis work consisted of the development of a ^{3}He STM, as well as research on Spin Excitation Spectroscopy in collaboration with the IBM Almaden Research Center.

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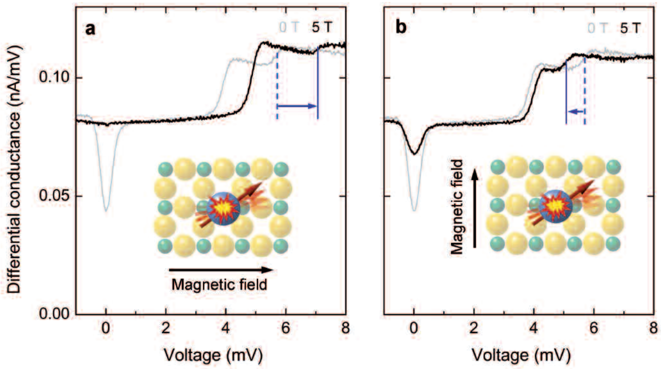

▲ **FIG. 6: When magnetic fields up to 7 Tesla are applied along the N-direction (a) or hollow direction (b), the observed excitation energies evolve differently. Specifically the 'blue' excitation (as defined in Fig. 5) goes up in energy in one case and down in the other. The insets show schematically what is happening: in (b) the magnetic field assists the excitation while in (a) it makes the excitation more difficult.**

HEARING GLASSES

AN INNOVATIVE APPROACH TO BEAT THE COCKTAIL PARTY EFFECT

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One often hears complaints from hearing-impaired people that their hearing aid is useless – or even counterproductive - under conditions where they need it most. This is strange. A hearing aid should make listening easier, not worse. How is this possible? The answer to this question has been known for a very long time. It is related to the fact that hearing impairment is often caused by reduced sensitivity and bandwidth of hearing, due to a reduced sensory-neural response of the ear caused by age, high noise levels or a disease.

This has two consequences. First, the threshold of hearing is raised. To compensate for this a hearing aid is an ideal companion, because it can amplify the sound that enters the ear. The second consequence is more difficult to handle. Mainly due to the reduced frequency bandwidth, a higher speech to noise ratio will be needed to understand speech. This is where many hearing aids fail, because they amplify wanted and unwanted sound by the same amount, leaving the speech to noise ratio unchanged. Under noisy conditions the sounds are often not just too weak; the problem is that the wanted sound simply cannot be distinguished from the noise. This is known as the cocktail party effect. Already in 1978 Plomp [1] published on this phenomenon and from his paper the conclusion can be drawn that the speech to noise ratio should be increased by at least 6 dB to give a hearing-impaired person the same ease of understanding speech under noisy conditions as a healthy person. However, research has shown that traditional hearing aids often amplify unwanted sound even more than wanted sound. This is mainly due to the directional characteristics of such a hearing aid when it is worn on the head.

This directly explains why the traditional 'omnidirectional' hearing aids turn out to be useless under noisy conditions. What one needs is adequate directional selectivity.

▲ **FIG. 1: Water waves reveal the position of the source by the direction in which they move.**

Looking for an innovative solution

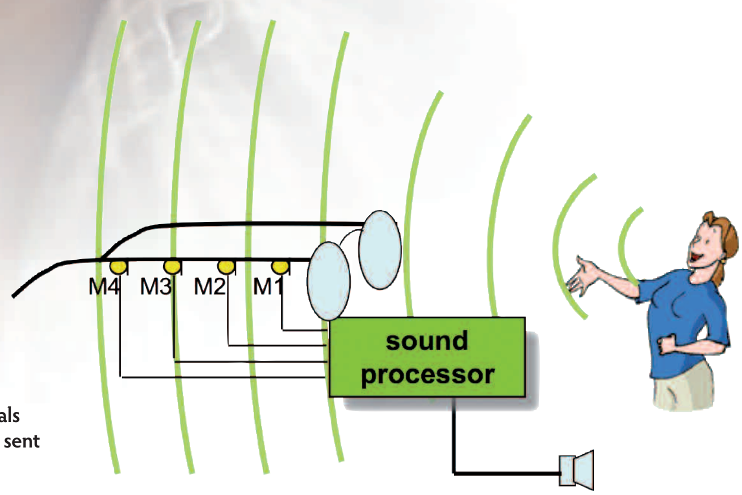
The answer to the problem seems easy: simply make a hearing aid directional, at least for situations where the wearer needs a better speech intelligibility. When facing a speaking person one needs amplification of sounds from the front, and attenuation of sounds from all other directions. This is at least a good solution when the speaker is near, such that the direct sound from the speaker is dominant over reflections and reverberation. This solution is well known in principle but not easily obtained in practice. What we need is a directional microphone (or *two*, for both ears). Moreover, to obtain directivity one needs to sample the sound field spatially over distances of several wavelengths. This may be compared with water waves (fig. 1). The position of the source (the disturbances caused by a stone thrown into the water) can be found by looking at the water surface and simultaneously observing the waves at different positions. It is not sufficient just to look at one point of the surface. This is exactly the problem that a hearing aid faces: for a good directivity it needs to observe or sample the sound field over some distance. But hearing aids are usually so small that it is almost impossible to do so.

This knowledge, plus the fact that there is a great need for good speech intelligibility in the hearing-impaired community, were the basis for a long term project at Delft University of Technology. Indeed, this topic became the subject of two successive PhD-thesis projects [2, 3].

It was clear from the start that microphone arrays had to be invoked to achieve a highly directional response, and that spectacles would be the ideal location for the microphone arrays. Since the spectacles are fixed to the head, the arrays turn automatically in the direction in which the wearer is looking. Looking at the speaker is not only polite: it also offers the possibility of lip-reading assistance!

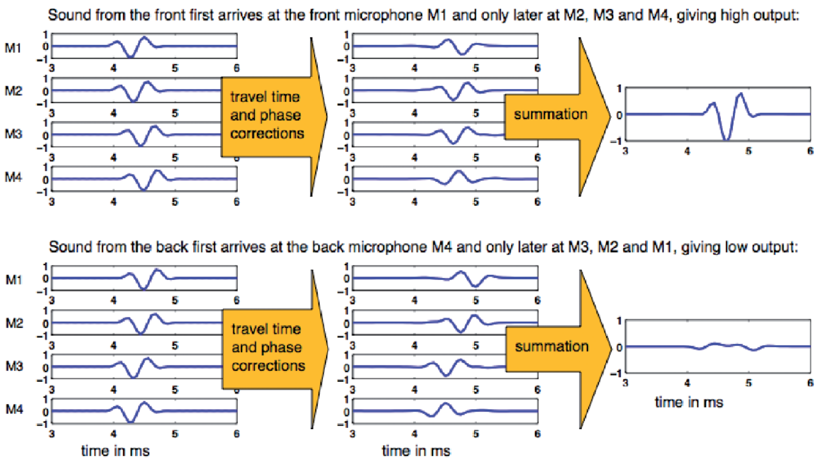
Early prototypes were downright ugly, but the hearing glasses which are now on the market have a fashionable design and look like normal spectacles (fig. 2). Each 'temple' (horizontal leg) of the spectacles contains four tiny microphones whose signals are fed to a chip for real-time signal processing, as shown in the block diagram of figure 3.

The first part of the signal processing is the so-called beam forming of the microphone array, which amplifies sounds from



▲ **FIG. 2:** The Varibel hearing glasses as worn with ear fittings.

► **FIG. 3:** Block diagram of the hearing glasses. The microphone signals are especially processed for high directional selectivity before being sent to the ears.



◀ **FIG. 4:** Principle of the directional beam former.

the front, *i.e.*, the direction in which the wearer is looking, while attenuating sound from the sides and from the back. The signal processing also includes frequency-dependent amplification and compression, necessary to obtain a comfortable listening level of the signals that are sent to the ears. This is achieved by small loudspeakers that are connected to the spectacles and feed the signals through tiny tubes to the ears (fig. 2).

Physical background

The operation of the hearing glasses relies mainly on the fact that differences in direction of incoming sound waves can be directly translated into differences in travel time to the microphones in the array. Obviously, this is done more accurately if there is a larger distance between the microphones. The temples of the spectacles offer sufficient spacing for this to be achieved with sufficient precision.

The principle of operation is further explained in figure 4. Sound coming from the front is processed in such a way that the microphone signals line up and their phases are optimized. In this case there is a high output. When applying this same processing to sounds coming from other directions, the signals do not line up and the output is low. This is illustrated in the figure for sound coming from the back.

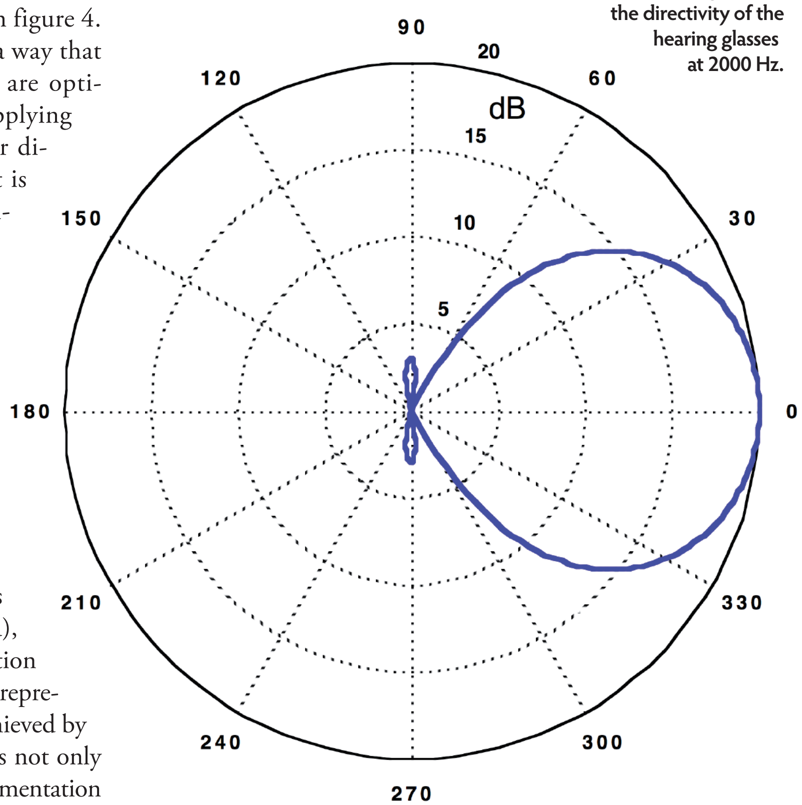
It must be noted that the array processing used here is not a simple delay and summation procedure, where signals are only time shifted for a desired listening direction. This well known principle would not be sufficient here, because the length of the microphone arrays of 72 mm is still small in relation to the wavelengths over a large frequency range. (The wavelength of a 1 kHz sound is 0.34 m). Instead, a much more sophisticated principle is used here, called optimized beam forming. In this method not the output from sound in a desired direction is maximized (as delay-and-sum beam forming would), but the ratio between sound from the desired direction and sound that enters randomly from all directions (representing the unwanted noise) is maximized. This is achieved by using specially designed phase shifts. This principle is not only more sophisticated; it also requires a very precise implementation of the filters that are needed in the microphone channels. This task cannot be carried out with sufficient accuracy by analogue techniques. Therefore we had to delay product development until low-energy digital signal processing (DSP) chips having the required functionality became available in the hearing aid industry.

Performance

With our optimized beam-forming method a very high directivity can be obtained, as shown in figure 5 for a frequency of 2 kHz.

The gain in directivity is expressed in the so-called directivity index or *DI*. Since the *DI* is frequency dependent it is usually weighted over the frequency range which is important for speech intelligibility. It is then called the speech-intelligibility-weighted directivity index DI_w. It is a measure for the attenuation of unwanted sounds from random directions as compared to the sensitivity in the forward direction. The processing of the hearing glasses gives a DI_w of 8 dB, which is extremely high for such a small microphone array of only 4 microphones over a length of 72 mm. Notice that this is significantly higher than the necessary increase in speech to noise ratio of 6 dB as found by Plomp [1]. Conventional directional hearing aids often use only two microphones that have to be placed close together, ▸

▼ **FIG. 5:** Polar diagram of the directivity of the hearing glasses at 2000 Hz.



because they must fit into the hearing aid. They usually do not show a DI_w higher than 3 dB.

The hearing glasses offer several user modes for different acoustic environments. In situations where a high directivity is not needed, a reduced directivity can be chosen by the wearer at will. In this mode the user can listen more easily to sounds from all directions, which is safer in traffic, and is also preferred for listening to music.

In conclusion

Hearing glasses provide the innovative answer to the demand from society for a highly directional hearing aid. It represents the result of a long-time research effort, carried out at the Laboratory of Acoustical Imaging and Sound Control of Delft University of Technology. Use is made of optimized beam forming by microphone arrays that are placed in the temples of a pair of spectacles. The signal processing is carried out with dedicated low-energy DSP-chips. The hearing glasses yield an effective directivity index up to 8 dB, which makes understanding speech much easier under noisy conditions. These hearing glasses have been on the market since April 2006 and are manufactured by the Dutch company Varibel. ■

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PHYSICS IN DAILY LIFE:

FEELING HOT, FEELING COLD

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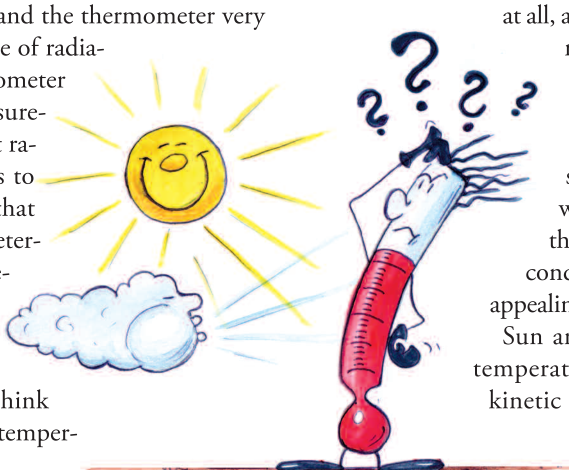
Even on a cold day, a bit of sunshine can make a tremendous difference. People will say things like 'It is supposed to be 15°C according to the forecast, but in the sun it's at least 25'. Although this may contain some truth in terms of heat balance, it is, strictly speaking, nonsense. There is no such thing as 'temperature in the sun'. How would one measure that? Different types of thermometers hanging in the sun would give widely different readings, depending on construction, optical properties and the like. The only decent definition of air temperature is derived from the mean kinetic energy of the molecules: $\frac{1}{2} m\langle v^2\rangle = \frac{3}{2} kT$. Radiation has nothing to do with it.

But measuring the kinetic energy of the molecules in a gas directly is not exactly a piece of cake. Therefore we use an indirect way: the thermometer. It's easy to use, but not always reliable. The problem is the low thermal conductivity of air. This makes the thermal contact between the air and the thermometer very poor. As a consequence, the influence of radiation is hard to suppress. If the thermometer is in the sun, forget a reliable measurement. But even in the shade, indirect radiation will cause our thermometers to be slightly optimistic. No wonder that meteorologist have strict rules for determining the temperature: thermometers must be placed inside well-ventilated casings, which are painted white, placed 1,5 meter above the ground, etcetera. If you think about it, it's almost a miracle that air temperatures are accurately measured at all.



Wind is another source of misunderstanding, if it comes to temperature. Obviously, if the wind blows around our body (or, in fact, around *any* object that is heated above ambient temperature), the heat losses by conduction will increase. The reason is that the insulating layer of air – normally a few mm thick – will become thinner once the wind blows. The effect is the same as if the air temperature were lower. That seemingly lower temperature is often called the 'wind chill' factor. Although this is a widely known concept, many people are still missing the point. An example is the journalist who concluded, using the wind chill table, that the water in his car's radiator would freeze well above the freezing point, if only the wind would blow…..

If we think about it, wind chill is an ill-defined concept. For one thing, it depends upon the clothing that we wear. For example, in the limit of infinite insulation, wind would not bother us at all, and the wind chill factor would become meaningless. All we can say for sure is that any correction for wind must asymptotically reach a limiting value if the wind speed goes to infinity. Consider bare skin: eventually, our skin would assume the air temperature, and the heat losses would be limited only by conduction inside our own body. Not an appealing prospect, if it freezes outside.

Sun and wind: both make the concept of temperature a bit fuzzy. Thank heaven that kinetic theory provides us physicists with a reliable definition.

Come rain or shine. ■

DEUTSCHES MUSEUM IN MUNICH

▲ Main building of the Deutsches Museum in Munich

It is not a common situation, that a single museum occupies an entire "island", but so does the German Museum of Masterpieces of Science and Technology in Munich. In Germany, the exhibition is better known as Deutsches Museum and it is the world's largest museum of science and technology.

When you enter the main building you find just what you would expect from a classical technical museum: Tall rooms filled with a huge number of machines, each with a little label next to it, and a lot of students walking around. You certainly wouldn't want to spend more than a few hours in such a museum, but what you see at first glance is only one of the oldest parts of the museum's collection. Several impressive exhibits, such as a V2-Rocket, will fascinate fans of this classical museum style. You will note that many of the exhibits are kept in operable condition all the time, but also that the signs and labels are not multilingual in the older exhibitions.

If you continue your walk through the ground floor you may be frightened by some very loud cracks. This is the definite sign that you're just missing the famous high-voltage show in the exhibition for electrical power transmission. Although this section is also a rather old one, it is an example for the museum's good cooperation with industry: All the exhibitions and their major experiments have been equipped by leading companies of science and technology and the experiments shown were state of the art in the time they were built. So even a physicist will be fascinated by a continuous 60 cm long electric arc generated by a 300 kV transformer and some other grand demonstrations you couldn't even do in some physics lectures.

As you walk on you will also find some of the modern exhibitions that offer exactly the "hands-on" experience most people like about a modern museum. So you can build your own bridge, measure the strain on a bridge-pier or test the advantages of different types of dams in the hall about bridge building.

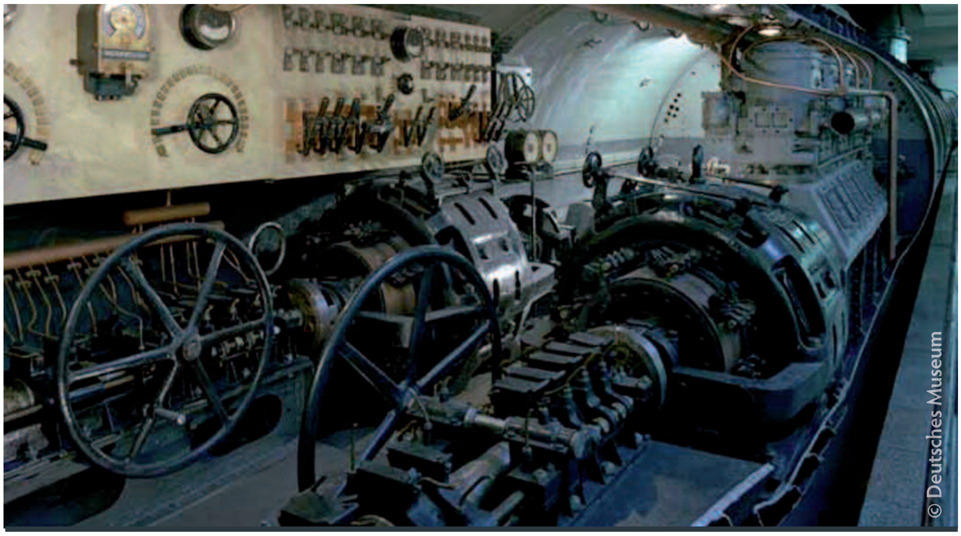
In the informatics section you will be pleased not only to see some historic telephones but also to find them attached to a working switching exchange that shows you how it would route your telephone call through Europe. When you walk through the less busy exhibitions it may often be helpful that many staff members enjoy giving you additional information if you ask for it. If you visit the museum with a group, it is no problem to get a guided tour through a specific exhibition. For ▸

▼ Human size Faraday cage

▶ Aeroplane exhibit at Deutsches Museum Flugwerft Schleißheim, established on a former airfield

me, it was very interesting to listen to a tour through the informatics exhibition where you did not only get to know how some old computers worked but also what all the employees had to do to keep them working and what the costs of ownership for these machines were like.

As a physicist it was a duty for me to visit the physics exhibition as well. You can find every single experiment shown in the basic physics courses in university but in addition to that, you can perform most of them by yourself. Beginning by varying your moment of inertia standing on a rotating disk you can continue by handling some really strong magnets until you reach the exhibition about energy generation where you can compare the CO_2 emission of different energy sources. You may be disappointed about the fact that the older parts of the physics or chemistry exhibitions haven't seen a facelift for quite a long time and that some experiments don't work at the moment but in the face of the great number of experiments you may excuse that. I enjoyed the creativity that was put into the pharmacy section for example, because you can walk into the inside of a human cell and while you get to know the causative organisms of today's major diseases you're sitting on a pile of giant pills.



▲ **The first German submarine (U1) from 1906**

Sections like this one will also fascinate children of an appropriate age but to provide interesting activities for younger ones as well, the museum has built up a children area where you can play various music instruments or try different lifting blocks by yourself. Children up to the age of 8 will have much fun playing there, which will make a day in the museum more relaxing.

Because the museum deals with a huge number of different topics, it has turned out that the museum-island doesn't provide enough space anymore. Therefore aeronautic and earthbound traffic have been relocated to two different locations inside and around Munich. Although these buildings don't provide the typical museum flair you'll be glad to find many hands-on exhibits like the simulation of a hydrogen-driven car. You're supposed to learn how to operate a Hofmann voltameter to convert the given electrical energy most efficiently into hydrogen and then to drive your hydrogen car with maximum range.

If you would like to pay a visit to the “Deutsches Museum”, you should keep in mind that it is absolutely impossible to see more than one third of its exhibitions within one day not including the external departments. Hence you won't have any problem filling a whole day if you're interested in science and technology and it may provide you with new insights into well-known inventions and discoveries. ■

▼ **Model of a human cell, scaled up by a factor of 350 000**

▶ **Exhibit of historic sports cars**

Martin Zimprich,
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Germany