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features special

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The origin of the elements of life

features

European Physical Society

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ditor D. Lee *(d.lee@univ-mulhouse.fr)*
cience Editor G. Morrison
esign and Layout P. Stearn

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cover
View of rising Earth about five degrees above the Lunar horizon. (image courtesy of NASA)

features

activities

NEWS FROM EPS

2005 The World Year of Physics

European Physical Society

At the Third World Congress of Physical Societies (Berlin, December 2000) the President of the EPS, Martial Ducloy addressed the delegates. He reminded the participants that physics is fundamental to our understanding of the world: it provides answers to such fundamental questions as the structure of matter, the properties of materials, the birth and fate of our universe and the origin of life on our planet. It contributes to our understanding of the environment and of the place human beings occupy in nature. Physics is an irreplaceable corner-stone of our culture. Moreover, physics has been, is, and will be, a major driving force of global technical and economic development - either directly or as an indispensable basis for other sciences, such as medicine, biology, chemistry, the geosciences and for most technological developments. In the 21st century some of the most important areas in research will be in climate change, new energy sources and energy storage, new materials, information technology, transport, health and environment. Scientific success and technical implementation in all these fields will be correlated to a sound knowledge base in physics.

However, in recent years, there has been a decline in the national budgets for physics research. The number of students at the university level studying physics is decreasing at an alarming rate. Global economic and cultural welfare has to be guaranteed by an understanding of the role of physics and an adequate supply of well-qualified scientists, in particular physicists and engineers a high standard of general education. Concerted action at the international level is necessary to emphasise the role and impact of physics in the economic and cultural development of the society and to increase public awareness and understanding. To this end, the Presidents and representatives of more than 45 Physical Societies from all over the world, unanimously decided to declare the Year 2005 as the World Year of Physics.

The main purpose of the World Year of Physics is to raise a worldwide public awareness for physics and more generally for physical sciences. The goal is for each physical society to encourage their national governments, school systems and industry to engage in a series of activities for the general public showing the importance of physics. M. Ducloy has been extremely active in promoting the World Year of Physics, contacting all EPS Member Societies, Divisions and Interdivisional Groups, other large physical societies such as the American Physical Society and IUPAP, as well as international organisations, UNESCO, the European Union in particular.

"Physics is an irreplaceable corner-stone of our culture"

The choice of the year 2005 as the World Year of Physics refers to the 100th anniversary of the "Miraculous Year" of Albert Einstein, when he wrote his legendary articles, providing the basis of three fundamental fields in physics: the theory of relativity, quantum theory and the theory of Brownian motion. Albert Einstein, who can be viewed as the first "international" physicist of the 20th century, realised most of his research work in Switzerland, Germany and the USA. Einstein, the physicist and the man, is a charismatic figure for the general public, and will be the emblematic "flag" for this World Year of Physics.

It is now time for EPS Members to use their influence, either as individuals or in a professional capacity to begin promoting the World Year of Physics in their own country. The success of the initiative will depend upon how convincing you can be. Let's go to work.

Advertising Manager Susan Mackie
Address 250, rue Saint-Jacques, 75005 Paris, France
tel +33 155 42 80 51 *fax* +33 146 33 21 06
email mackie@edpsciences.org

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

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The origin of the elements of life

M.G. Edmunds
Department of Physics and Astronomy, Cardiff University, Wales

About 10% of your body weight is hydrogen. The simple proton nuclei of the hydrogen have not been altered since they formed in the Big Bang some 14 billion years ago. But 60% of you is oxygen, 20% is carbon and 3-5% is nitrogen, elements that have been made in nuclear reactions *since* that distant strange beginning of the Universe. In this article I will try to set out what we know of how and where these elements – so crucial to life as we know it – were formed. We must look at not only the details of the nuclear reactions inside stars, but also at the mechanisms which will deliver these nuclei into the Galaxy, and how their abundances will have built up over time.

We'll start with oxygen. This is the heaviest of the three CNO elements, but the one whose site of birth is probably best understood. Most of the oxygen in the present-day Universe was produced in nuclear reactions just before or during the spectacular stellar explosions known as Type II supernovae. These occur at the end of the life of stars that began with about eight times or more mass than the Sun. The amount of energy that can flow through a star, from its nuclear generation in the star's hot core and up to the surface, is strongly dependent on the mass of the star. A star that is ten times the mass of the Sun has perhaps a thousand times the solar flow of energy. So even though a more massive star has proportionally greater reserves of nuclear fuel than the Sun, it squanders its inherited hydrogen at a prodigious rate, converting it to helium in a well-known cycle of quasi-catalytic nuclear reactions that we shall later look at in detail. The result is a very short lifetime – only a few million years – before an inexorable and rapid sequence of structural changes occurs. As the hydrogen fuel is exhausted deep in the star's core, the core's density and temperature increase under gravitational contraction. Other reactions become possible as the higher relative speeds overcome the electrostatic coulomb barrier repulsion of higher charged nuclei and tunnel through to reaction. The most obvious reaction might seem to be

$$^{4}He + {}^{4}He \rightarrow {}^{8}Be + \gamma$$

but it has long been known that the beryllium 8 is unstable, decaying back almost immediately to two helium nuclei. Only if a third helium strikes the beryllium before it decays can onward reaction occur to form carbon:

$$^{8}Be + {}^{4}He \rightarrow {}^{12}C + \gamma;$$

giving what is known as the "triple-alpha" reaction, because the overall result has been the fusion of three alpha particles. The rate that this reaction must have to explain the lifetimes of certain types of star led to the famous prediction (in the early 1950's) by the late Sir Fred Hoyle that the second reaction must be resonant. And indeed subsequent laboratory measurements did find the required excited energy level in the ^{12}C nucleus, inspiring the Nobel Prize-winner Willy Fowler into a lifetime's work in nuclear astrophysics. The carbon can react onwards by the addition of another alpha particle to give oxygen:

$$^{12}C + {}^{4}He \rightarrow {}^{16}O + \gamma$$

Surprisingly, the rate of this reaction is still rather poorly known – as discussed in a recent article by Rauscher and Thielemann in this journal. The problem is the very small reaction cross-section at the energies relevant for stellar reactions, which makes it impossibly slow to perform direct laboratory determinations at these energies. Extensive indirect research has taken place in the last thirty years to try and pin it down – since the rate is crucial in determining the relative abundances of the C and O nuclei produced in the "burning" of helium. References to the best current estimates are given in Imbriani *et al.* 2001.

Having used up most of the helium in its core, a massive star will continue through a series of heavier nuclear fuels, each yielding less and less energy despite increasing temperature and pressure. Quite soon the core is no longer able to adjust its pressure balance quickly enough, and its evolution changes from being almost hydrostatic to hydrodynamic – collapsing inwards under the influence of gravitation while temperatures and reaction rates rise steeply. Explosion results from a sudden stiffening of the equation of state in the core as nuclear densities are reached, causing an outward-propagating shock wave that is helped along by the push of neutrinos. Further nucleosynthesis occurs as this shock wave passes, and disrupts the star in a Type II supernova explosion. The enriched material exploding out at tens of thousands of kilometres per second into the interstellar material will deliver the freshly synthesised oxygen for incorporation into future generations of stars and planets. But even before the explosion occurs, considerable material will have been lost from the star by a less extreme, but still quite energetic, stellar "wind". Such winds probably provide the major delivery mechanism for the carbon created in the triple-alpha mechanism, but which has escaped further processing to oxygen.

As outline above, massive stars ($M > 8M_{\odot}$) are the best candidates for the main source of carbon and oxygen. We now look at the mechanism by which nitrogen is formed. Recall that we mentioned the quasi-catalytic chain of reactions that convert hydrogen into helium. The main chain results from successive

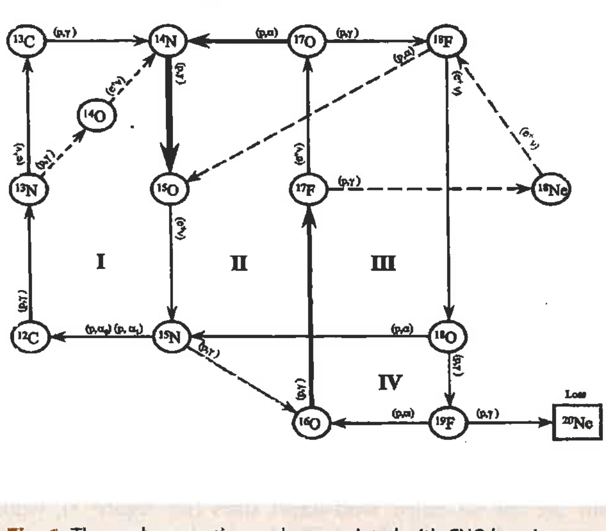

Fig. 1: The nuclear reaction cycles associated with CNO burning (Diagram from Adelberger E.G. *et al.*, 1998, *Rev.Mod.Phys*, **70**, 1265.)

proton captures and beta decays. Suppose we start with the main isotope of carbon, ^{12}C, then:

$$^{12}C + p \rightarrow {}^{13}N + \gamma\,;\ {}^{13}N \rightarrow {}^{13}C + e^{+} + \nu\,;\ {}^{13}C + p \rightarrow {}^{14}N + \gamma$$
$$^{14}N + p \rightarrow {}^{15}O + \gamma\,;\ {}^{15}O \rightarrow {}^{15}N + e^{+} + \nu\,;\ {}^{15}N + p \rightarrow {}^{12}C + {}^{4}He$$

The net result of which is the conversion of four protons into a helium nuclei. The positrons produced will quickly annihilate in the dense plasma. There is a (much slower) side chain feeding oxygen into the cycle at ^{14}N:

$$^{16}O + p \rightarrow {}^{17}Ne + \gamma\,;\ {}^{17}Ne \rightarrow {}^{17}O + e^{+} + \nu\,;\ {}^{17}O + p \rightarrow {}^{14}N + {}^{4}He$$

Now in the main chain, it is the $^{14}N(p,\gamma)^{15}O$ which is by far the slowest reaction. This acts as a "bottleneck" - rather like repair works on a road causing the traffic to back up - with the result that the abundance of ^{14}N builds up. So although the reaction chains are "catalytic" in the sense that the *sum* of the abundances by number of the nuclei C, N and O is conserved, the actual result is essentially the conversion of ^{12}C (quickly) and ^{16}O (more slowly) into ^{14}N. Not surprisingly, nature is a bit more complicated than just the single "CNO Cycle" describe above - subsequent work suggested a second (CNO "bi-cycle"), and then a third ("tri-cycle"!) and fourth, as shown in figure 1, but the original cycle is the dominant mechanism. Rather surprisingly one of the reaction rates in the main chains here - the $^{17}O(p,\alpha)^{14}N$ capture - was in error in the literature for many years. I recently tried very elementary calculations of the evolution of element ratios in the chains and kept finding large over-prediction of the $^{17}O/^{16}O$ ratio - and it was with some relief that I found more modern determinations (Angulo *et al.* 1999) show that the old reaction rate was nearly two orders of magnitude too low - with the new (but still uncertain!) rate suitably reducing the ^{17}O abundance. The expected equilibrium element and isotope ratios will be a function of the stellar interior conditions of pressure and temperature. Typical predicted equilibrium element ratios for N/O and N/C are 10, 50 - quite different from the solar system values of 1/10, 1/4 - indicating that although these chains may be the source of our nitrogen, only a fraction of the carbon and oxygen in the universe has been processed in this way. The prediction of the $^{12}C/^{13}C$ isotope ratio is also interesting - CNO cycling tends towards giving a ratio of 3 to 4, very much lower than the solar system 90, but low values around 6 to 10 are indeed observed in the atmospheres of some giant stars where CNO processed material has been mixed up to change the atmospheric composition, the mixing being caused by convective motions inside the star.

We now have the basic nuclear processes. But the identification of where they occur, or rather of which type of site dominates the supply of the particular element, continues to cause controversy. Massive stars are certainly involved for both oxygen and carbon. Both helium "burning" alpha-capture reactions, and CNO cycles of proton capture will occur at shell-like regions with the appropriate conditions within the star. Towards the end of their brief lives very strong winds of gas are driven off the surfaces of massive stars, reducing their mass and revealing the layers deep inside the star where the products of the recent nuclear reactions can be seen. The winds deliver the synthesised material into interstellar space. Particularly good illustrations of this behaviour are the so-called Wolf-Rayet stars (see figure 2), whose spectra and classification indicate overabundances of either freshly formed carbon (WC stars) or subsequent processing of the carbon via the CNO cycle into nitrogen (WN stars) together with very strong gas outflows. These (quite rare) stars represent a short stage in a massive star's life, which we just happen to have glimpsed. Extensive stellar evolution computations (e.g. Maeder 1992) can follow these changes, and indicate how much new carbon, nitrogen and oxygen is released to the interstellar medium in the stellar winds before the even more spectacular release in supernovae explosion at the end of the stars' lives. The release is shown by Andre Madaer's diagram in figure 3, a picture that is now some years old but still remains the best that I know. To identify the sites that *dominate* CNO nucleosynthesis, our own efforts (Henry, Edmunds & Köppen 2000) used the results of such calculations, and also of models of the evolution of rather lower (in fact "intermediate" 2–8 M☉) mass stars. Lower mass stars might be important because, although individually they cannot contribute as much as a more massive star, there are many more of them. Star formation favours the small. Their element production can again be by CNO processing to produce nitrogen (from the C or O seed) and - in their later life as giant stars - alpha-capture reactions. Our method is to look at the chemical composition of a wide range of systems - both stars in our own Galaxy, and gaseous nebulae in a wide range of other galaxies. It is then possible to plot diagrams of the observed carbon to oxygen (C/O, see figure 4) and nitrogen to oxygen (N/O, see figure 5) ratios as a function of the

Fig. 2: A Wolf-Rayet star with its nebula including stellar wind gas with newly synthesis carbon and nitrogen. (Photo from Anglo-Australian Observatory)

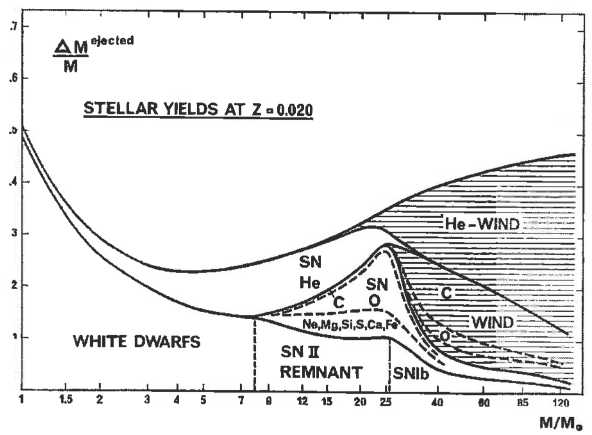

Fig. 3: Schematic diagram by Maeder (1992) illustrating the zones of newly synthesised material released from massive stars into the interstellar material. The vertical axis is the ejected mass fraction (or remnant in the lower part), and the hatched areas show the strong winds. The calculations assumed the stars initially had the same elemental composition as the Sun.

oxygen to hydrogen (O/H) ratio in these objects. Note that we are now dealing with *number* rather than *mass* ratios of element abundance. The O/H ratio acts as a good indicator of the general amount of star formation, stellar evolution and consequent synthesis of heavy elements that has gone on in a system. The bulk of this oxygen originated in Type II supernova explosion of massive stars. The systematics of these diagrams, combined with the stellar nucleosynthesis predictions, allow us to have a pretty good guess at the dominant sources. Obviously we also have to fold the relative birthrate numbers of stars of different masses into the calculations.

The C/O diagram suggests that relatively more carbon is produced at low oxygen abundances than at high – otherwise the trend should have been horizontal on the figure. This may well be related to the fact that stellar winds are more intense in stars with high oxygen abundances (probably due to the details of the wind generation mechanism). Quantitative agreement with massive star calculations (c.f. Maeder *op cit*) implies that it is indeed massive stars (of order 8 solar masses or more) that contribute *most* of the carbon. This is despite the know existence of less massive stars which do show overabundances (by up to 100 times) of carbon in their atmospheres. The overabundant carbon must have come from internal nucleosynthesis, but these so-called "carbon stars" are not contributing the bulk of the interstellar carbon. Indeed, the nomenclature "carbon star" is rather misleading since carbon is still a fairly minor constituent of such stars, compared to hydrogen or helium. But once the ratio of carbon-to-oxygen exceeds unity in a stellar atmosphere it has a radical and very noticeable effect of the spectrum of the star. The oxygen atoms can no longer tie up *all* the carbon atoms in carbon monoxide molecules, and the spectra of C_2 and other carbon-based molecules dominate the spectrum. It is still unknown exactly how much of the carbon from either massive or lower mass stars is delivered to the interstellar medium in solid form – the carbon vapour can condense (in certain conditions) in the stellar atmospheres. This is a very important problem in the study of the origin and evolution of interstellar dust in galaxies.

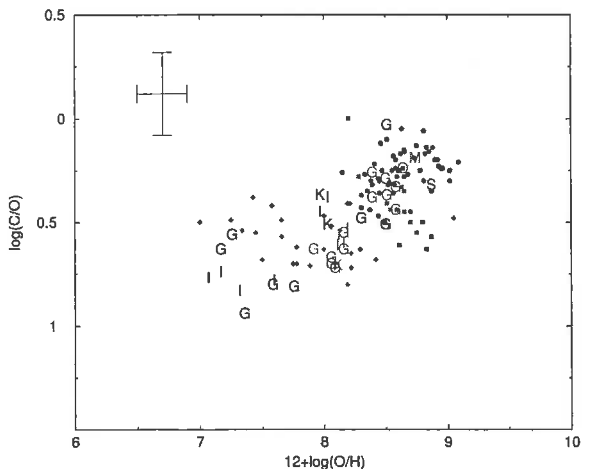

Fig. 4: Logarithmic plot of observed carbon-to-oxygen ratios (C/O) against oxygen-to-hydrogen ratio (O/H) for gaseous nebulae (i.e. essentially the interstellar material) in our own and other galaxies, together with some stars. The details of the nomenclature and sources can be found in Henry, R.C.B., Edmunds, M.G. and Köppen, J. 2000.

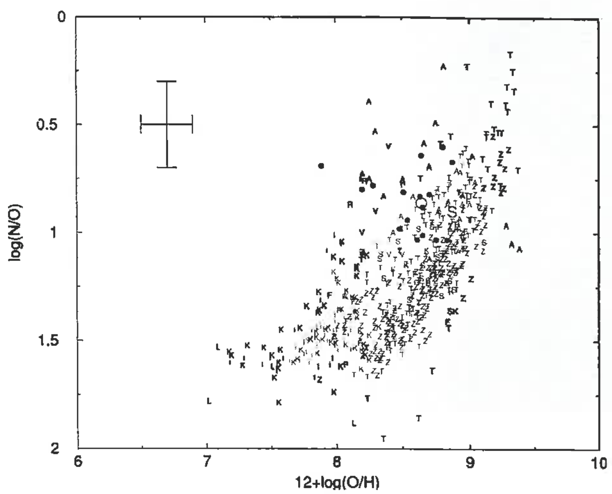

Fig. 5: As for figure 4, but showing nitrogen-to-oxygen ratios (N/O). In both this figure and figure 4 the sun is shown as "S", although an important new determination (Prieto *et al.* 2001) would reduce the sun's oxygen abundance (moving the point diagonally in the figure) by about 0.2 in the log.

For nitrogen the situation is reversed – it is the intermediate mass stars (perhaps 2 to 6 $M_\odot$) which are the main contributors. We should introduce a subtle complication here, based on where the carbon and oxygen that is CNO processed into nitrogen comes from. If the carbon and oxygen is that which came into the star when it formed out the interstellar material, then the nitrogen produced is said to be "secondary" – since it was produced out of pre-existing seed nuclei. Elementary models for the chemical evolution of galaxies then predict that the N/O ratio will increase linearly with increasing O/H. If the star *itself* produces the carbon and oxygen by helium burning, and then that material is subsequently CNO processed, then the nitrogen produced is said to be "primary". In this case we would expect that the N/O ratio would be constant with increasing O/H, except perhaps for some small effects due to abundance-induced changes in stellar structure or stellar winds. The appearance of the N/O versus O/H diagram indicates that the nitrogen has a *primary* source at low oxygen abundance, but a dominating *secondary* source at higher abundances. Indeed at higher abundances the behaviour is even steeper than the expected linear behaviour, probably due to the aforementioned abundance effect on overall stellar evolution. Computational models of the so-called "intermediate" mass stars between about 2 and 8 solar masses indicate (e.g. van den Hoek and Groenenwegen 1997) sufficient production (or "yield") to account for the observed nitrogen abundances. Clear evidence of material in which C and O have been processed into N can be seen in the spectra of planetary nebulae. These planetary nebulae (see figure 6) are the glowing gas thrown off by intermediate mass stars after the red giant stage of their life, as they settle down to fade away as white dwarfs. It is not yet finally resolved whether massive stars might make a significant contribution in systems with very low element abundances. This is important because low abundances represent the very earliest stage of galactic evolution. If only the intermediate mass stars contribute, the delivery of nitrogen to the interstellar medium lags behind the rapid (10^6 years) massive stars' contribution of oxygen. The N/O ratio can then be used as a kind of "age" indicator until the few 10^8 years

Fig. 6: A planetary nebulae. The name "planetary" originates historically with their disk-like appearance in primitive telescopes. The nebula gas has been ejected as a violent stellar wind from the star at the centre, and will often show evidence of enhance nitrogen abundance. (Photo from Anglo-Australian Observatory)

later when the intermediate star production begins to be released. Recent calculations (Cheffi *et al.* 2001) suggest that even the very first generation of 4 – 8 solar mass stars with *no* pre-existing heavy elements may be able to produce carbon and subsequently process it to nitrogen. Whether even more massive stars can do the same and be a significant source of nitrogen remains to be seen.

Overall we now have a picture in which the relative amount of oxygen in the interstellar medium builds up with time as successive generations of stars form and their massive stars explode as Type II supernovae. Carbon is made mainly at a very slightly earlier stage in the life of these stars, and released in strong stellar winds. Nitrogen comes mainly from intermediate mass stars. Over time, nitrogen becomes relatively more abundant compared to oxygen, while carbon relatively declines slightly. It is interesting to speculate at what point in this build up there are sufficient materials to produce life. Of course, the necessary conditions for the formation of stable planets will probably have to be reached first – and for this iron and silicon seem necessary, at least on our current (and probably rather naive!) views.

Almost all theories of star formation agree that the first generation will have contained – and *perhaps* have been dominated by – stars above a few solar masses. So the basic building blocks of life - carbon, nitrogen and oxygen – will have been present in small quantities from within a million years or so of the birth of very first stars. We ourselves are the archaeological remains of nuclear reactions that occurred from the earliest stars right up until 4.6 billion years ago when the formation of the solar system effectively cut us off from the interstellar medium.

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Will machines start to think like humans?

Artificial versus natural Intelligence

G. Binnig, M. Baatz**, J. Klenk**, and G. Schmidt***
**IBM Research Division, Zurich Research Laboratory, CH-8803 Rueschlikon, Switzerland,*
***Definiens AG, Trappentreustr. 7, D-8803 Munich*

Thinking is a complex procedure, which is necessary in order to deal with a complex world. Machines that are able to help us handle this complexity can be regarded as intelligent tools that support our thinking capabilities. The need for such intelligent tools will grow as new forms of complexity evolve, for example those of our increasingly globally networked information society.

In order for machines to be capable of intelligently predigesting information, they should perform in a way similar to the way humans think. First, this is a necessary prerequisite in order that people can communicate naturally with these machines. Second, humans have developed sophisticated methods for dealing with the world's complexity, and it is worthwhile to adapt to some of them. Such "natural thinking machines" (NTM) with their additional conventional mathematical skills can leverage our intellectual capabilities.

It appears that NTMs require new software approaches as well as novel hardware solutions, which might possibly be based on nanotechnology. However, in this paper we concentrate on the principles of "natural computing" (performed by NTMs), independent of their realization in actual soft- or hardware.

The capabilities of today's machines are still far from humans' capabilities. However, natural computing has not yet reached its limits. Existing approaches combined with new concepts and ideas promise significant progress within the next few years. The vision of natural computing as a new concept presented in this paper is based on our understanding of the principles of human thinking combined with the functional principles of biological cell systems.

Established approaches

The field of artificial intelligence knows several different approaches to model natural thinking. They include semantic networks [1], Bayesian networks [2], and cellular automata [3], but the most prominent examples are neural networks [4] and expert systems [5]. At the same time, modern programming tools frequently have a touch of natural computing [6] to enable programmers to generate code for increasingly complex problems. We believe that the basic principles of the established approaches discussed below will be fundamental elements of future natural computing. In the section "Triple-S network" we will show how they can be combined into one tool and propose new aspects to be added.

Expert systems (ESs) express the logic of human thinking in tree-like decision structures. This yields satisfactory results for medium-sized systems. For increasingly complex structures, however, this approach reaches its limits. The net-like aspects that bring associations, abstractions, and uncertainties into play—possibly the most important feature of humans' talent to deal with complexity—is not simulated adequately.

Neural networks (NNs) obviously concentrate on the network aspect. They represent a very basic form of natural computing. In essence, NNs simulate the fundamental functions of the nano- and microstructure of the brain, its neurons, and their interconnections. Input signals are usually connected to this network and propagate in a certain way throughout the network. How the signals propagate can be controlled by weighting the connections between the nodes. These weights can be adjusted automatically by means of a training procedure.

Tasks such as recognizing faces, which might not be easily dealt with in logical terms, are the strength of NNs. Extremely complex tasks, however, would require that large amounts of interwoven complex concepts, like those present in our brains, can evolve automatically. This would be equivalent to reinventing the evolution of our mind from scratch.

Semantic networks (SNs) and (semantic) *Bayesian networks* (BNs) have certain similarities with NNs, as they also employ probabilistic methods. Here, however, the nodes and, in some cases, the links are connected to individual semantic expressions, i.e., they have names or expressions associated with them. Therefore these networks have the advantage of being accessible locally in their internal structure to humans. A disadvantage compared to NNs is that the network structure has to be created manually, but this structure can later be checked for its plausibility and modified if necessary because the nodes and links carry semantic, human-understandable meaning. Limitations arise when these networks become large and complex, in which case it becomes increasingly difficult to oversee the overall performance of the network.

For BNs the structure of the network is built manually, and the weights can be trained. Unlike in NNs, the weights on the connections to a node are not treated as being independent from one another. Technically this is achieved by means of matrices of weights on the nodes instead of weights on the links. As a result the number of weights might become extremely large.

In SNs the links as well as the nodes can carry meaning. For instance, simple facts such as "legs are part of a person" and "man is more specific than person" can be expressed using hierarchical links such as "is part of" and "is more specific than".

SNs and BNs generally use global algorithms that operate on the networks to calculate excitation values of the nodes. Some SNs contain "procedural attachments" at the nodes, which are triggered when their nodes' excitations exceed a certain threshold.

Programming languages. The most common way to introduce artificial intelligence is to write a conventional computer program in a common language such as C++ or Java to perform, for example, a cognition process. Typical examples are search engines for texts based on statistical methods or filters in images that extract certain objects. The task here is to find the smartest algorithms and combine them in the smartest way. This is done manually by programmers, and it is up to them to make the program appear intelligent. If in an image of a computer chip a broken line is found automatically, or if a chess-playing computer beats the world champion, there is certainly intelligence behind this process. It is virtually impossible to write an error-free program of reasonable complexity, and it is equally impossible to oversee what such programs do. That is why programs have to be debugged, their performance tested, and revised again and again. If programmers had to write these programs in machine language, the task would be nearly impossible. Modern computer languages enable programmers to write code on a higher level, i.e., more like the way they think and less like how the processor works. Hence modern programming languages are tools that reflect human thinking to a certain extent, and therefore constitute a kind of natural computing.

If a person could teach a computer in a natural way how to perform a certain task, one certainly would call it a natural thinking machine. If one looks into the history of programming languages, one finds that they have evolved in this direction. Object-oriented and other modern languages indeed use many natural concepts such as classes and inheritance.

Cellular automata are instruments to compute complex situations. The idea behind cellular automata or cellular machines (CMs) is quite natural: neighboring objects influence each other. A large number of so-called cells in a regular geometrical arrangement are used. The cells usually have discrete states that are influenced by their relationships with their neighbors. CMs can be regarded as primitive networks, but their dynamics can be extremely complex. In principle (disregarding performance) any kind of computation can be performed with them.

Triple-S network, fractal machine

If one combined all of the above-mentioned methods or at least certain aspects of them into one technology, one could conceivably accumulate their individual strengths to produce a more powerful machine. Figure 1 proposes such a method in the form of a particular knowledge network. As discussed below it is a *self-organizing, semantic, self-similar network*, or a triple-SN for short. A triple-SN is essentially a kind of hierarchical world knowledge network containing knowledge about objects, their properties, and their relations, as well as processing knowledge about what to do when certain kinds of objects are present in the real world. By "real world" we mean the varying input that interacts with the triple-SN. This input could be an image, a text, or any complex structure.

There are nodes and links that carry semantic meaning (similar to SNs) as well as procedural attachments, which are shown as Jani (singular: Janus: a god with two faces). Some links represent ES-like logic ("and", "or", and other more complex functions). Links and nodes carry weights that can be trained (similar to NNs). Links can be linked to other links, which allows (in addition to other aspects) dependencies to be introduced among them (similar to BNs).

The most unusual feature of our triple-SN is the combination of a hierarchical structure and the large number of procedural attachments [7]. This constitutes a form of generalized CM: the state (activation) of a Janus depends on the state (excitation) of the node to which it is attached, whose state depends in turn on the states of the neighboring nodes, Jani, and links. In the triple-SN, nodes and connections are grouped into subnetworks. If these subnetworks are also regarded as nodes with associated states, we end up with a hierarchical, generalized CM with similarities across the hierarchies, which we call a "fractal machine".

When such a network interacts with complex inputs, inheritance (in the sense used by modern programming languages) comes into play: input objects (acting as instances) inherit Jani from nodes or links (acting as classes) to which they fit best. This inheritance can also be regarded as the activation of procedural attachments. The objects in the input change their states stepwise according to the influence of their neighborhood (similar to CMs). Some of the Jani represent classification procedures, which compare classes and instances with each other, whereas other Jani network or group the input objects (segmentation). Thus, in a stepwise procedure of alternating classification and segmentation, the activated Jani transform the initially unstructured input into a hierarchical network. The structure of the input network therefore becomes increasingly similar to the triple-SN itself. For example, at the onset, an input image might consist only of various pixels. In the course of the procedure, a hierarchical, networked structure of the image evolves in steps to produce shapes such as houses with neighboring objects such as streets, which ultimately evolve into a city. Attributes are attached to the objects and their relations. In the triple-SN this structure is also expressed as one of several possible structures.

With this approach, more objects and relations are created than necessary. Some of them are discarded. Others, which are relevant of themselves or useful for creating objects on a different hierarchical level, are kept. The creation of objects and their relations on and across different hierarchical levels is equivalent to transforming information into knowledge. This includes context as it is represented by the local network neighborhood of a particular object.

The automatically alternating procedures of classification and segmentation of the input objects is a new aspect, which we call self-organizing or affective computing. Two other aspects that have previously been overlooked are generic computing and self-similar (or fractal) computing. All three mechanisms represent important mechanisms of nature and will be discussed further.

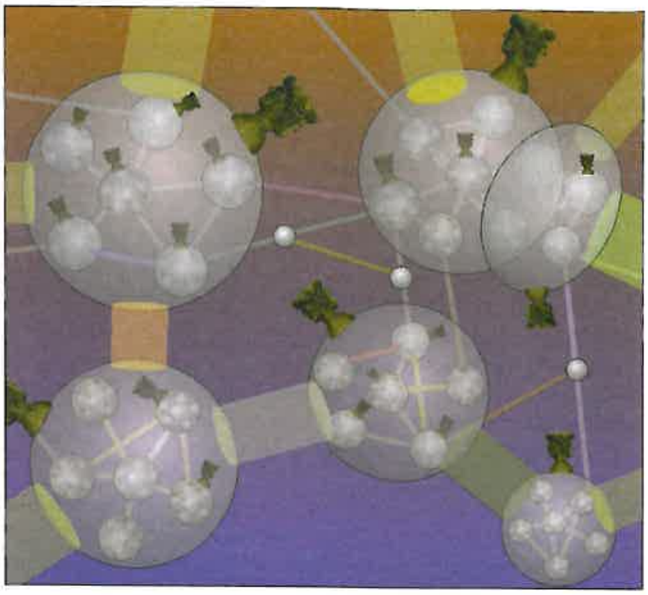

Fig. 1: Triple-S network: self-organizing, semantic, self-similar network; a kind of hierarchical world knowledge network. It contains knowledge of objects, their properties, and their relations, as well as processing knowledge on how to handle certain classes of objects and relations when their instances are present in a complex input. The hierarchical structure of objects containing networks of smaller objects and locally attached algorithms is visualized by Jani (head with two faces). The triple-S network uses activated Jani to structure and network complex inputs as well as to classify the evolving objects and their relations. Jani are activated when the attached objects and relations become excited beyond a certain threshold. Their particular operation is influenced by the local structure of the network. The networking and structuring of the input transforms information into knowledge and, to a certain extent, constitutes an automatic "understanding".

Affective (self-organizing) computing. Let us assume for a moment that a living organism can be regarded as a kind of intelligent "computer" that automatically responds to changes in its environment by starting certain "programs". Our brains are clearly capable of doing so. In the course of our lifetime we learn a huge amount of different behaviors and strategies. They are all coupled to certain classes of situations. Only if we assign a situation to a certain class (classification) will we begin to apply the strategy that fits the situation (affect). All other strategies are dormant. It is important to note that, apart from strategies of action, different classification methods also represent different strategies, which are usually classification-driven as well. For example, with the help of classification our mind is able to concentrate on certain aspects of a given thing and to subject it to a more detailed classification.

Something very similar is true for a primitive living organism such as a cell system. One could regard the code of the DNA-strand present in each cell as programs that represent strategies. In this sense the genes (the relevant segments on the DNA strands) represent individual programs, and the exons (the smaller segments of the genes) represent subprograms.

Activating these individual programs means reading the code of a gene and transcribing it ultimately into a protein. In this sense the protein represents the activated gene and actually performs certain tasks. Similar to the affective behavior mentioned above, at a given moment or at a specific location most of the strategies (in this example, the genes) are not activated. The pertinent genes are only transcribed if required by the location or the momentary situation of the cell. It is a kind of classification process that triggers the activation in a way similar to affective behavior. Here again some of the activations triggered might represent detailed classification procedures.

There are a large number of steps involved from reading code to producing RNA-strands to generating protein code to folding the protein a specific way. Many things can "go wrong" in producing the final protein. For example, if the molecules and proteins needed during the various steps are missing, the protein cannot be formed properly. There is doubtlessly intelligence behind the processes in the cell, for we can assume that if something goes wrong in one of the steps, the final protein might in fact be discarded. Then, in a sense, the total process from transcription to folding of the protein can be regarded as a classification process. However, there is more to it than an isolated classification process. As several other types of proteins are involved in the production of a particular protein, the system constitutes a complex network with a generalized cellular machine character: the state of a gene (its activation) depends on the state (activation) of other genes.

A DNA strand looks like a one-dimensional piece of information. The same is true for a text, for example, or a thesaurus. In fact all these strings represent network because the objects therein are related to one another. If the meaning of a word or an image object (its state or classification) depends on the meaning of other words or objects in its neighborhood, they form a network with this CM character.

Generic or fractal computing. The proteins in a cell are part of certain processes called pathways. It is interesting to note that several proteins are usually part of a pathway and that one kind of protein can be part of many different pathways. The latter circumstance would be equivalent to a computer subprogram that constitutes an essential part of very different programs, such as an image-processing or a translation program. For primitive subprograms such as the command "copy", this is already the case today. This command can be applied to objects in images, in texts, or to entire documents. In general, however, subprograms cannot be used in any other program.

If the function of proteins were not based on such a generic principle, then a complete, new set of proteins would be required for each pathway and the genetic code would be orders of magnitude longer. The same is true for a computer program with subprograms that can be used repeatedly for very different tasks: the total length of the source code can be reduced dramatically. The variety of what the programs can do results from the variety of ways in which these subprograms can be combined. We suspect that a large portion of evolutionary effort went into formulating genes in a generic way, and this portion is possibly even larger than the portion that went into finding functional genes. How could such a short code in our DNA strands describe a system as complex as a human being? The answer is generic processing.

For computer programs this could apply as well. In the past, programs have been formulated to perform certain tasks. In the future they might be formulated in a generic way, so that their components can be used for other kinds of programs as well. If (sub)programs are formulated in such a way that they can be combined with other programs, the complexity of a new task can be handled not by writing a completely new program, but simply by creating a new combination of existing ones. The richness of the new program results from the richness of all possible combinations.

We believe that this property will be essential to handle complex computing tasks of the future. A future search engine might have to analyze the text as well as the images in documents, or other kinds of data. If the task is simple and both analyses can be done independently, the problem could be solved in a conventional way. If certain parts of the text relate to certain parts of the image, which is usually the case, the analysis is entangled, and a detailed cooperation of various programs is needed. This cooperation is much easier if the programs have similar structures, just like cooperation between people is easier if they speak a common language. The simplification of the interfaces is what makes the difference. If people speak the same language, they need no translation.

The simple command "copy" in an operating system of a computer is useful across many hierarchies. A character, a word, an image, a text, a document, or a folder can all be copied. In a cell, the generic structure is present over many hierarchies. Proteins are part of a single pathway, but they are also part of the entire functionality of the organism. In our brains, the concept of similarity can be applied to practically everything and across all hierarchies. Two different objects in an image might be alike, two words might be synonyms, two texts or two images might have similar meanings and so on. We call a system with generic components that are used on many different hierarchical levels a "fractal" or "self-similar" system.

We expect that it will soon become possible to extract meaning from complex inputs such as documents, regardless of the format of the content. Computers will "understand" multimedia documents to a still somewhat primitive extent, but well enough to constitute a useful intelligent assistant for humans.

Acknowledgment

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Gerd K. Binnig received numerous awards including the Nobel Prize in Physics (1986), for the development of the scanning tunneling microscope, which he invented together with Heinrich Rohrer. The scanning tunneling microscope and the atomic force microscope which he invented later made it possible to image and study structures and processes on the atomic scale. These instruments, which serve as tools for investigations of phenomena of the smallest dimensions, play a key role in nanoscience and nanotechnology.

Binnig's current research is concentrated on micro- and nanosystem techniques, specifically on the development of a novel nanomechanical data storage system, and on the theory of "Fractal Darwinism", which he developed to describe complex systems.

Watching paint dry: Magnetic resonance imaging of soft condensed matter

Peter J. McDonald and Joseph L. Keddie
Department of Physics, University of Surrey, UK

Solid, crystalline matter is now remarkably well understood, thanks mainly to the efforts of physicists during the last century. Building on this success, there has been an increasing trend among physicists in the past few decades to turn their attention to *soft* condensed matter – or "squidgy" stuff. Soft matter displays either viscous (liquid-like) or elastic (solid-like) behaviour, depending on the time scale of the measurement. Examples range from gelatine and pastes to liquid crystals and melted polymers. Physicists' interest in soft matter arises in part because it displays an intriguing universality in behaviour and can be described by "coarse-grained" models that ignore atomistic and chemical detail. A characteristic of soft matter is its tendency to arrange itself at hierarchical levels, such as the layering in liquid crystals and the ordering of colloidal particles into a cubic array. As such, the relevant length scales range between the molecular (nanometer) up to tens of micrometers.

Many types of soft matter, such as concentrated emulsions, are not stable under high vacuum and are perturbed by even light mechanical forces. Phases that are confined to small volumes can only be studied by techniques that do not disturb the confining phase. Soft matter is continuously undergoing thermal fluctuations, and so its structure is dynamic. Because of all of these characteristics, it is not feasible to probe soft matter by many analytical techniques. Non-invasive and fast techniques are required.

Natural substances, such as cells and tissues, can also be considered to be soft condensed matter. As aptly stated by William Burroughes, we humans are "soft machines." In 1973 two groups independently developed a technique to "look inside" these soft machines. Sir Peter Mansfield and colleagues at the University of Nottingham and Paul Lauterbur at the State University of New York in Stonybrook both announced that the resonance of magnetic nuclei could be exploited to non-invasively provide cross-sectional images in the technique known as magnetic resonance imaging (MRI).

MRI soon became the imaging modality of choice in medical research and diagnosis. It is now coming of age in the study of soft condensed matter, too. The stage through which all new microscopies go – that of taking "pretty pictures" as the primary objective – has truly passed. Now, enabled largely by physicists across Europe, scientists are starting to answer some questions of real import to the study of soft matter.

Principles of MRI

Magnetic resonance relies upon the fact that magnetic nuclei of atoms, such as the hydrogen proton, precess in a magnetic field at a frequency directly proportional to the field strength. The frequency, which is in the radio-frequency (r-f) range, is detected via the current arising from the transient response of the nuclei to a resonant r-f stimulus. This current is induced in a detector coil around the sample. Magnetic resonance imaging, as depicted in figure 1, is achieved by superimposing on the sample a magnetic field gradient. The resonance frequency now encodes position. Fourier transform of the transient response yields an intensity *versus* frequency plot which directly correlates to a one-dimensional density *versus* position profile. Imaging in multiple (2 and 3) spatial dimensions is achieved with multiple acquisitions under gradients in different directions followed by multi-dimensional Fourier transformation.

The lifetime of the transient decay (known as the spin-spin relaxation time, T_2), or equivalently the resonance linewidth ($1/\pi T_2$), as well as the relaxation time necessary to re-establish thermal equilibrium after excitation (known as the spin-lattice relaxation time, T_1) are exquisitely sensitive to motion at the molecular level. In a field gradient, they are sensitive to macroscopic motion such as flow. By carefully tailoring the sequences of r-f pulse stimuli and the strength and sequencing of the magnetic field gradient applications, it is possible to sensitise the signal and thereby to map a wide variety of motion-sensitive parameters, including T_1 and T_2, as well as self-diffusion coefficients D_s and flow velocities v.

It is this capability to non-invasively visualise the structure and dynamics of soft condensed matter that gives MRI considerable advantage over other microscopies and that more than compensates for its relatively poor best achievable resolution (a

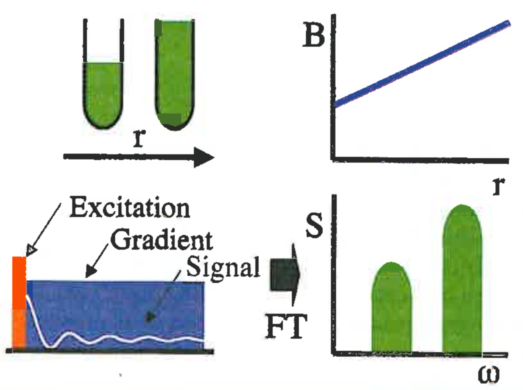

Fig. 1: The principle of magnetic resonance imaging: The Larmor equation states that the resonant frequency of magnetic nuclei, ω, in a magnetic field is directly proportional to the field strength, B, according to $\omega = \gamma B$, where γ is the nuclear magneto-gyric ratio. For spatial resolution, a switched gradient field ($g.r$) is superimposed on a static field (B_0) so that the resonant frequency $\omega = \gamma(B_0 + g.r)$ encodes position, r (top right). In this example, the sample consists of one full and one half-full test tube of water (top left). The hydrogen proton NMR signal is excited with an electro-magnetic radiofrequency excitation pulse and is observed as a transient response in a suitable receiver (bottom left). Fourier transformation of the response yields a frequency spectrum, S(ω) which has a direct one-to-one correspondence with the sample density profile (bottom right).

few μms). Dependent on methodology, temporal resolution can be as good as 100 ms, but for most of the studies reported here is more like 10 to 100 seconds.

Those exploiting the dependence of relaxation parameters, i.e. T_1 and T_2, and transport parameters, such as D_s and v, on local environment to probe, with or without spatial localisation, the structure of soft matter are a very diverse group of researchers. At one extreme are researchers such as Brian Hills (UK) and Mike McCarthy (USA) who make detailed micro-structural studies of foodstuffs and their basic ingredients. Others, such as Lynn Gladden, Ken Packer (both in the UK) and Igor Koptyug (Russia) explore liquids in confined media and related transport phenomenon. Olle Söderman (Sweden) is not alone in making detailed studies of emulsions. Rainer Kimmich (Germany) has made detailed analyses of the motional spectrum of polymer chain in the melt and in confined geometries. The scope of much of this work is revealed in recent proceedings [1, 2]. Few researchers, however, have specifically looked at colloidal films, such as paint, with MRI.

Aqueous colloids, in which sub-μm solid or liquid particles are dispersed in water, are ideal subjects for MRI. Here we review the application of MRI to the drying of layers of polymer colloids, or, less prosaically, to drying paint. We show that this proverbially tedious subject is in fact a rich source of physical interest and unsolved problems.

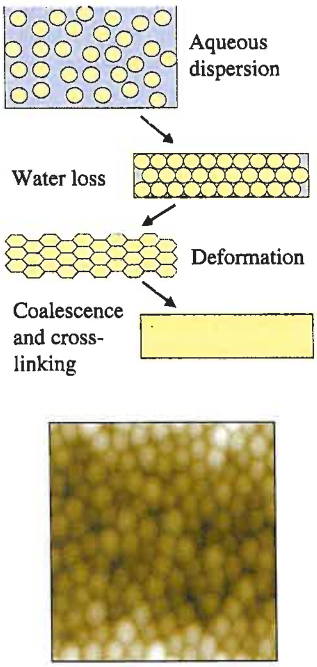

Fig. 2: The drying of an aqueous dispersion to a solid film occurs in stages. First, the water is lost by evaporative drying. Second, the particles in the resultant close-packed array deform to fill the available space, and third they coalesce by inter-diffusion to form a film. Lastly, sometimes a chemical reaction "ties" the molecules together - or "crosslinks" them - to create a hard film. Beneath the schematic diagram is an image (obtained with an atomic force microscope) of the surface of a film when the particle have packed into an array (stage two) but have not coalesced. Image size is 5 μm × 5 μm. A key question is whether water evaporation is completed before, during or after the particle deformation.

Imaging of Aqueous Colloids

In spite of the fact that aqueous colloids dry every day in thousands of guises - not least including spilt coffee [3] - this remains a problem of considerable theoretical interest and practical importance. MRI can offer unique insights as it can map the evolution of the water distribution in a drying layer as a function of time. By way of introduction, figure 2 summarises the key stages of the process by which polymer particles form a paint film.

Pioneering MR studies at the University of Surrey began with a study of convex layers of emulsions made from a viscous oil (alkyd) [4]. An emulsion is a finely-divided mixture of one liquid in another - in this case, alkyd droplets in water. Alkyd emulsions are being developed as a new, environmentally-friendly gloss paint. MRI reveals the fine detail of the transport of the alkyd and the water phases as the water evaporates. This work went on to consider much more generally the drying of aqueous dispersions.

Figure 3 shows cross-sectional images of the water content as a function of time after casting a dispersion of polymer particles on a glass substrate. The water can freely evaporate upwards. The images were obtained using a standard high field (9.4 T) super conducting NMR magnet equipped with standard switched current winding gradients for imaging. The images reveal how the drop dries laterally with the edges drying long before the central regions. Quantitatively describing this is not so simple. As the edges dry, so the particle concentration grows non-uniformly and this drives a lateral transport of water across the drop. Water flows from the central region, in which particles are dispersed in water, to the edge region, where they are packed closely together. The rate of water loss at the centre is thus more rapid than the average, and that at the edge is slower.

At what point in the process does drying from the edges first occur? Water is initially pinned to the edge of the layer because of strong capillary forces. Just as the capillary force draws water upward against the pull of gravity, so too can it prevent water from moving inward from the edges of a film. In this case, the tiny space between particles of radius r in contact creates a capillary having a pressure that is proportional to σ/r, where σ is the surface tension of water. At some instant, marking what is called the "open time", the capillary pressure is no longer strong enough to prevent the water from receding from the film edge.

Routh and Russel [5] at Princeton University have investigated this phenomenon theoretically in great detail. The critical parameters include particle size, film thickness, evaporation rate, surface tension, and viscosity. Uniform drying is favoured by larger particles, slower evaporation rates and thinner films. The analysis predicts a normalised time for drying of a film's edge as a function of reduced capillary pressure p_c. Using MRI data, such as that just presented, the Surrey group provided the first experimental test of Routh and Russel's predictions [6]. The data shown in figure 4, obtained from MR experiments, shows an encouraging agreement with the theory.

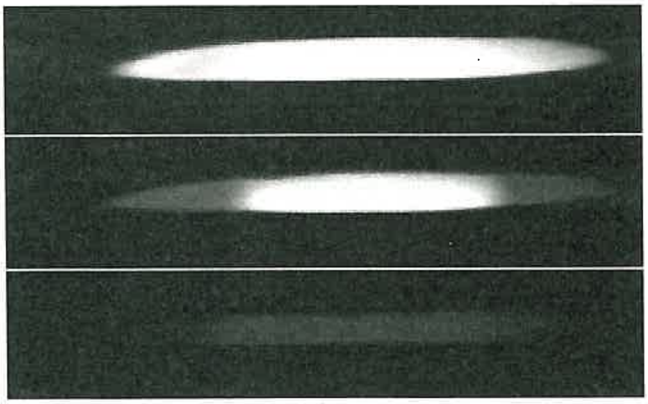

Fig. 3: Three images extracted from a series showing the drying of a latex film from the edges towards the centre [6]. From top to bottom are images of the initial wet film and after drying for three and six hours. The image intensity indicates the water content: the white regions contain particles still dispersed in water; the grey regions correspond to a close-packed array of particles with water flooding the interstices. The field of view is 22 mm wide by 2 mm deep.

features

A Novel Magnet for Films

MR images, such as those already presented, do offer some information on the vertical profile of thick layers but thinner layers obviously require greater spatial resolution. At lower water concentrations and when accessing non-aqueous phases, the T_2 of the nuclei is much shorter. Studies of thin layers, low water concentrations and non-aqueous phases all require much greater magnetic field gradients than can normally be achieved using switched current-windings. To that end Paul Glover (now at the University of Nottingham) and colleagues designed a small portable permanent magnet with a uniform (magnitude) magnetic field in the horizontal plane and with a very strong field gradient in the orthogonal vertical direction [6]. This field profile is carefully tailored to provide best achievable spatial resolution across planar samples. The magnet (figure 5), which is dubbed GARField (Gradient At Right angles to Field), is ideally suited to the study of dispersion layers. Moreover, because a superconducting magnet is not required, GARField reduces the cost of MR profiling considerably.

We now cite contrasting examples of GARField's use.

Creaming. Just as cream rises to the top of whole fresh milk, colloidal particles in other dispersions likewise separate from the liquid because of density differences. The theory of creaming (and the opposite phenomenon of sedimentation) is well-developed but, because of the difficulty in non-invasively probing small particles in water, experimental work is still catching up. The use of NMR diffusometry to determine the size of emulsion droplets has long been well-established in a technique known as q-space microscopy. A more recent development is q-space microscopy coupled with imaging. In our application, the resultant MR profiles can determine how factors such as particle size and the viscosity of the water influence the creaming rate and the particle distribution.

Larger liquid droplets separate from a dispersion by creaming at a faster rate than smaller droplets. Naturally, therefore, larger droplets are found at the top of a cream layer. MRI studies of cream layers in simple oil-in-water emulsions confirm this expectation. The addition of water-soluble polymers to an emulsion can cause emulsion droplets to cluster together under the action of osmotic pressure resulting from depletion effects. MR analysis has found that these clusters – or flocs, as they are known - create cream layers that are much less stratified. The droplet size distribution is roughly constant throughout the layer.

Uniformity of drying. Most of us have touched the surface of a drying latex paint and noticed that its surface has formed a skin-like layer that covers a wetter region below. GARField is an ideal tool to probe the uniformity of drying in the direction normal to the surface of a paint layer.

The problem can be considered to be a competition between two effects, illustrated in figure 6. The particles diffuse by Brownian motion, described with a Stokes-Einstein diffusion coefficient D, and thereby will re-distribute themselves uniformly in a dispersion. When water evaporates at a rate E, however, particles become more crowded together near the surface as the water between them is removed. If the rate of re-distribution by diffusion is slower than the rate of particle crowding caused by water evaporation, then the water concentration will become non-uniform with less water near the surface. For a wet film with a thickness of H, Routh and Russel [7] propose a Peclet number (given as HE/D) to gauge the relative effects of diffusion and evaporation.

Recent GARField experiments have explored the correlation between the Peclet number and the distribution of water normal to the surface of a film. The predictions are supported by initial experiments. Additives that increase the viscosity of the aqueous phase and slow down diffusion favour non-uniform drying, whereas slow rates of evaporation lead to a uniform water distribution.

Particle deformation. The water loss in a packed bed of hard particles - such as sand - is not as simple as one might first expect. Air flows in to replace the water and creates a rough meniscus in a mechanism known as "viscous fingering". When drying soft particles, the problem is more complicated, because the particles are not static. The water phase can create a capillary pressure that "pushes down" on the particles and can sometimes deform them. Evaporation from a

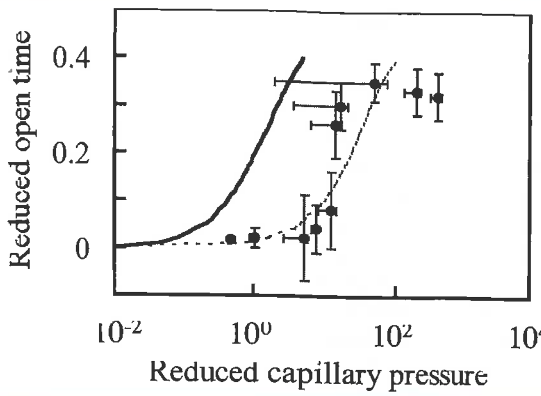

Fig. 4: The solid line shows the reduced open time of a drying aqueous dispersion against reduced capillary pressure, as predicted by the model of Routh and Russel [5]. The open time is a measure of the time required for the water in the drop to begin to recede from the edges. The reduced capillary pressure depends on factors of geometry, viscosity, and surface energy. The data points are derived from MR images of 10 different drying films, spanning three orders of magnitude of reduced capillary pressure [6]. Although the data follow the broad shape of the simulation, the predicted capillary pressure where the open time rises steeply is too low. The dashed line is a re-evaluation based on less realistic geometric parameters.

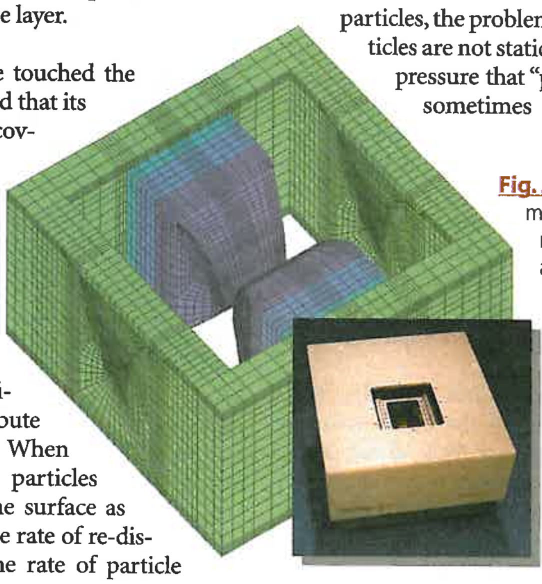

Fig. 5: A wire-frame drawing of the GARField magnet, a small bench-top permanent magnet with shaped pole pieces which give a horizontal constant (magnitude) field in the horizontal plane and a strong in-built field gradient in the vertical direction ($17\ T\ m^{-1}$ at 0.7 T). It offers optimal resolution (≈10 μm) for profiling soft-solid layers and has revolutionised our ability to examine paint layers, among other systems [7]. The inset shows the magnet as realised by Resonance Instruments Ltd. The curved pole pieces of the magnet are seen in the centre of the box, which is 60 cm wide.

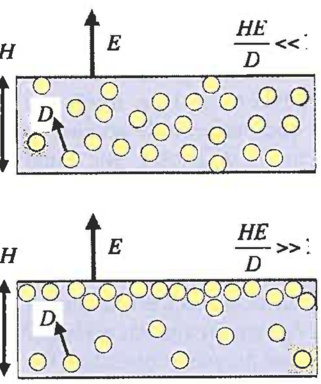

Fig. 6: If a dispersion evaporates (*E*) slowly, then diffusion (*D*) across the thickness of the layer (*H*) can maintain a uniform distribution of particles. If, on the other hand, evaporation is more rapid, then this is not true, and particles accumulate near the surface. Soft particles will then coalesce to create a "skin" layer that can inhibit further drying [8].

packed layer of deformed particles is slower than from a layer of perfect spheres. Thus, in a cyclical relation, water can influence the particle packing and shape, and the particles can, in turn, influence the rate of water loss.

There is an ongoing debate in the literature about the various reasons why small, soft particles deform from their spherical shape when making a film. Does the deformation occur in the presence or absence of water? The answer is dependent on the ease of deformation of the particles in comparison to the strength of the forces acting upon them. MRI reveals how water is distributed as the particles are deforming. The technique thus provides clues to the dominant mechanism.

Crosslinking. In the last stage of film formation (figure 2), polymer molecules in adjacent particles are chemically "tied"

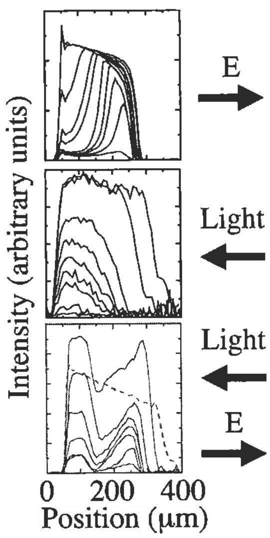

Fig. 7: The drying of a photo-initiated crosslinking latex exemplifies the use of GARField. There are three primary components in the system: polymer particles, crosslinker and water. The first time sequence of profiles, at the top, shows the effects of water evaporation, *E*, from a polymer dispersion layer without crosslinker cast on a glass substrate. The decreasing signal intensity with time shows water loss, as the remaining polymer gives no signal. As expected, water is lost first from the exposed upper surface (right side). The middle sequence shows the polymer and cross-linker only. The polymer softens the polymer, and due to the enhanced molecular mobility, it yields a measurable NMR signal. Light is incident on the upper surface (right side of the profiles). After an induction period of 90 minutes (shown in the first two profiles, nearly overlaid), signal intensity is lost from the lower side of the film in contact with the glass substrate (left side) as crosslinking occurs. The initial delay and the slow crosslinking near the surface are due to dissolved oxygen that continues to ingress the surface during the experiment. Oxygen inhibits the chemical reaction. The complete colloidal system (shown at the bottom) is turbid. As a result, light does not fully penetrate to the lower region and hence crosslinking is slower there. Oxygen inhibits the crosslinking reaction near the surface, as before. Because of these factors, the layer curiously crosslinks fastest in the central region. It has been possible to model this process quantitatively [9].

together, or crosslinked, to create a solid film. New experimental paint formulations utilise a crosslinking reaction initiated by visible light. The paint layer hardens when light falls on it. It is vital that particles coalesce before crosslinking, or a dry powder layer will result. Figure 7 shows how GARField can reveal information not achievable by any other means. The photo-initiated crosslinking latex studied here crosslinks (hardens) in the central layers of the film first [8].

Bulk Surfaces. An EC-funded project, MARWINGCA, in collaboration with Trätek (Sweden) and WSAB Lignomat (Germany), exploits yet another use of GARField: surface drying of porous substrates. In this case the substrate is wood, which is a heterogeneous, porous and complex structure. Wood drying is of considerable practical relevance in the timber industry, and the correct optimisation of the process is of commercial value. Traditionally, modelling has assumed rather simple surface boundary conditions (e.g. constant evaporative flux or constant surface concentration, etc), but now GARField is able to provide the detailed information by which surface layer inclusive models can be tested and refined.

Outlook

Soft condensed matter continues to attract the interest of physicists. As outlined here, MRI has already yielded valuable insight into phase morphology, flocculation, particle coalescence, and drying phenomena. Largely unexplored, however, is how shear stresses affect the structure and phase distribution of soft matter, including paints. Imaging under the application of shear will provide a wealth of information to complement what is known about the static systems. Developments in instrumentation will pave the way to examine transport and structure in the lateral direction of films. "Watching paint dry" will continue to provide interesting questions for the condensed matter physicist.

Acknowledgements

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Laser spectroscopy in development

Sune Svanberg, Lund Institute of Technology, Sweden

Laser spectroscopy has developed into a very rich field of scientific and technological endeavour with applications ranging from analytical spectroscopy to Bose-Einstein condensation in dilute alkali gases. It has provided completely new possibilities in fields as diverse as the study of combustion processes, atmospheric monitoring, water and vegetation surveillance, cultural heritage preservation and medical diagnostics. With the fast development of laser sources and auxiliary equipment, including computers, the applications of laser spectroscopy can become more widespread.

Optics, spectroscopy and laser applications are suitable high-tech fields for the promotion of physical research in developing countries, because it is reasonably basic, it connects to real-world applications and it can be affordable. This has been observed by organisations such as the Optical Society of America (OSA), the International Commission on Optics (ICO), and the European Physical Society (EPS). The activities in the field co-ordinated by Gallieno Denardo at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste have been particularly notable. It helped establish the African LAM network (www.lam-network.org), presently co-ordinated by Ahmadou Wague, Dakar.

Diode laser atomic spectroscopy

The emergence of diode lasers useful for spectroscopy was a very important factor in establishing laser spectroscopy in less favoured regions. As an example, a small workshop was arranged in Lund in July of 1996 with participants from Cape Coast (Ghana), Dakar (Senegal), Khartoum (Sudan) and Nairobi (Tanzania) to build experimental set-ups, primarily for spectroscopy on rubidium vapour. Resonance cells with separated ^{85}Rb and ^{87}Rb isotopes were skilfully prepared by the University of Latvia, Riga. Each group built a complete set-up for diode laser absorption spectroscopy and could measure ground state hyperfine structure, the isotopic shift and Doppler broadening. Using saturation spectroscopy even Doppler-free signals could be observed, and upper-state hyperfine structure be studied. The project was financed jointly by the ICTP and the IPPS, Uppsala (director: Lennart Hasselgren). After the workshop the equipment was shipped to the different sites in Africa, and a Lund graduate student, Peter Kauranen, travelled around to the universities to help making everything functioning on site.

Laser-induced fluorescence

As a follow-up on the African diode-laser spectroscopy project an applications programme involving laser-induced fluorescence was proposed. At the Lund Institute of Technology a compact fluorosensor, based on a violet diode laser and an integrated spectrometer had been developed and successfully applied in vegetation monitoring and skin cancer diagnosis. The Lund group has a long experience in both these fields, which has relevance also to developing countries. The fact, that the hardware for these cutting-edge technology devices cost only 10,000 Euro, including a powerful lap-top computer for experiment control and data collection, made it a very realistic project. A one-month workshop, with the same title as the present article, was arranged in Lund in the spring of 2001, where two people from each of the African universities mentioned above participated, together with representatives from three further developing countries: Zimbabwe (Harare), Tunisia (Tunis) and Equador (Quito). Typically, a senior researcher and a student represented each physics department. In total six compact fluorosensors were assembled and tested by the enthusiastic participants, to be taken along home for local research. A picture from the system integration is shown in Fig. 1. The experimental work was mixed with intense lecturing on atomic and molecular spectroscopy, environmental monitoring, laser medicine and other applications. The Zimbabwean and Senegalese groups also comprised senior medical specialists (Dr Ntkomo Ndlovu, Radiation Therapy Unit, Harare and Prof. E. Malik Diop, ENT Department, Dakar) to facilitate collaboration between physicists and physicians in the fields of tissue diagnostics and photodynamic tumour therapy, in a similar way as is pursued since long at the Lund University Medical Laser Centre. The participants could attend diagnostics and treatment sessions of cancer patients, organised by Katarina Svanberg.

The fibre-optic fluorosensors are presently used in a variety of projects and further ones are being planned. Application fields are within the environmental, agricultural and medical fields. The project was financed jointly by the IPPS (Uppsala) and the Swedish Developmental Board SIDA/SAREC (project officer: Claes Kjellström).

Fig. 1: *(below left)* Gabriel Somesfalean, LTH (centre), provides an assisting hand to graduate student Ben Anderson (left) and Paul Buah Bassuah (right) in the integration of their Ghana fibre-optic fluorosensor. The operations are being supervised by Nejm-Eddine Jaidane, University of Tunis.

Fig. 2: *(below right)* Cesar Costa, Escuela Politecnica Nacional, Quito (second left) and Kenneth Kaduki, Nairobi (right) together with Lund graduate students Gabriel Somesfalean and Sara Pålsson in front of a set-up for high-resolution diode-laser set-up, now transferred to Harare.

Gas in scattering media absorption spectroscopy (GASMAS)

A further technique of diode laser spectroscopy with affordable equipment and numerous applications is the newly introduced Gas in Scattering Media Absorption Spectroscopy, with the acronym GASMAS. The first paper on this technique, developed in the Lund group, had actually been published only 3 months before the 2001 workshop. A complete assembly for GASMAS was integrated during the workshop and was then shipped to Harare, within a project supported by SIDA/SAREC. A set-up for saturation spectroscopy on rubidium isotopes, similar to the ones already functioning at four other African sites, was also integrated for the Harare group and provided good training also for the all the workshop participants (See Fig. 2).

So what is the essence of the GASMAS technique? We will answer this question with reference to Fig. 3. It is a technique to study gas dispersed in scattering solids and liquids, observing that free molecules have a uniquely narrow linewidth compared to the matrix material. Normally, an extremely high resolution is not applied when studying solids or liquids, since there are no narrow features to resolve. If instead single-mode diode laser radiation is injected into the not too highly absorbing medium there will for natural materials frequently be a strong scattering and the light emerges diffusely as shown in Fig. 3a and b. If the laser is tuned to an absorption line of, e.g. molecular oxygen, the oxygen in the pores of the material will make its narrow imprint in the emerging light. By wavelength or frequency modulation techniques, routinely applied in diode laser spectroscopy, even tiny features can be detected using the type of appartur shown in Fig. 3c. By the multiple scattering in the material the pathlength is strongly prolonged helping to increase the signal. The GASMAS technique emerged from experience obtained in Lund in the fields of diode laser spectroscopy, atmospheric laser radar, and optical mammography. The free oxygen in such diverse media as wood, marble, plastics, polystyrene, fruits and flour was successfully studied. Numerous applications in many fields, including environmental control, process steering and medicine can be envisaged using the new technique. A particularly interesting aspect is that diffusion processes can be conveniently studied: the sample is just exposed to a different atmosphere, for instance nitrogen gas, for some hours and then the time constant for the re-invasion of the atmospheric oxygen into the sample is measured! In a first example it was found that the diffusion time constant for a particular sample of polystyrene was 44 minutes. By measuring the linewidth of the signal the internal pressure in a sample can be measured! Clearly, many different gases can be assessed in different wavelength regions.

The GASMAS technique, being new, exciting and affordable (a complete set up is about 20,000 Euro) was considered to be particularly interesting for helping building research infrastructure in developing countries. Apart from the Harare facility, there are advanced plans for similar work at other locations. Presently, Benjamin Anderson from Cape Coast and Omar Marcillo from Quito are performing GASMAS experiments in Lund, together with local graduate students Mikael Sjöholm and Gabriel Somesfalean.

The three different topics introduced at the African sites - high-resolution laser spectroscopy of free atoms, molecular gas monitoring in natural scattering media, and diode-laser induced fluorescence in natural samples are complementary activities. The diode laser technology is common and the laser units can be used in all three activities. While being affordable, the technology is cutting edge, and applications are realistic and also understandable to local governments. The diode laser set-ups have a

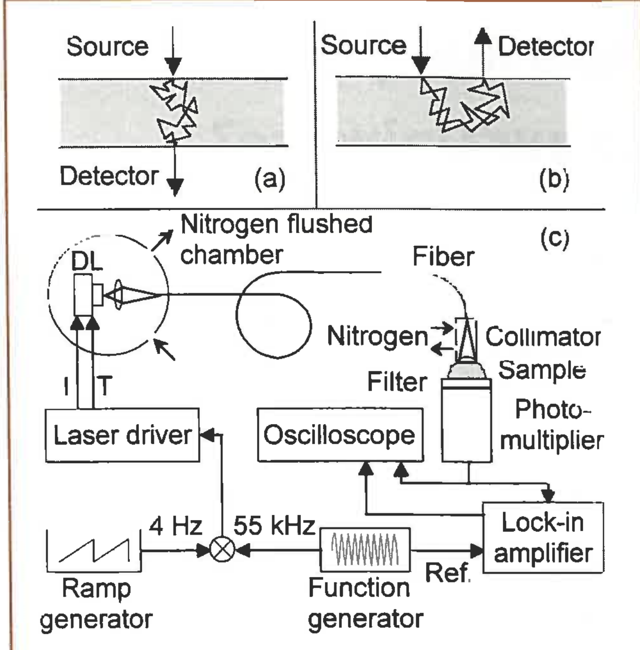

Fig. 3: Description of the GASMAS technique. In a) and b) it is shown how narrow-band diode laser radiation is injected into a porous scattering media and the emerging light is detected in two geometries. c) shows how a diode laser tuned to an molecular oxygen line around 760 nm is wavelength modulated to detect the sharp absorption signal in the light reaching the photomultiplier. Ambient oxygen is flushed with pure nitrogen.

wide applicability from use in lecture demonstrations and for advanced laboratory training in physics courses, to Master and PhD projects. With the availability of new tuneable sources such as quantum cascade lasers, a very broad wavelength region is reachable and rich possibilities for affordable further developments are evident.

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How many dimensions to our Universe?

Pierre Binétruy
LPT, Université Paris-Sud and APC, Université Paris 7, France

Even though this idea of extra spatial dimension may seem borrowed to the world of science fiction, physicists have grown used over the last century to the idea that there might be some compact dimensions. Of course not the three dimensions that we are used to, but some new dimensions of such a microscopic size that we would not be aware of their existence, unless we probed microphysics.

The first such attempt came from T. Kaluza [1] and O. Klein [2] in the 20's[1]. Their ideas were based on the following analogy: in general relativity, distances depend locally on the gravitational potential; one may thus imagine new dimensions such that the generalised distance depends also on the electromagnetic potential. This may lead to a unified theory of gravity and electromagnetism and, as such, immediately attracted the attention of Einstein [3].

More explicitly, the special theory of relativity of 1905 writes a invariant distance element in spacetime as

$$ds^2 = -dt^2 + dx^2 + dy^2 + dz^2.$$

In the general relativity theory of 1917, gravitational potentials curve spacetime:

$$ds^2 = -(1-2\Phi_g + 2\beta\Phi_g^2)\, dt^2 + (1-2\gamma\Phi_g)\ (dx^2 + dy^2 + dz^2),$$

where Φ_g is the gravitational potential and β, γ are post-Newtonian parameters, in the early formulation of Eddington (1922). Kaluza and Klein introduce a fifth dimension measured by the coordinate x_5. Electromagnetic potentials "curve" this extra spatial dimension:

$$ds^2 = -(1-2\Phi_g)dt^2 + (1-2\gamma\Phi_g)(dx^2 + dy^2 + dz^2) - \Phi_e dt dx_5 + \mathbf{A}.\mathbf{dx}\, dx_5 + dx_5^2,$$

where Φ_e and $\mathbf{A}$ are the scalar and vector electromagnetic potentials.

This idea has been revived later in the context of string theory. The fundamental objects in string theory are not pointlike but have one dimension in space: they are microscopic strings, closed or open. This property is believed to cure one of the problems of gravity at the quantum level, the appearance of infinities related with the small distance behaviour (high energy or ultraviolet regime). But this is believed to occur only if the symmetries of the string theory are fully respected at the quantum level, which happens only for a specific number of spacetime dimensions[2].

It is usually believed that the extra spatial dimensions are compact and microscopic: an upper value of 10^{-16} m on their size comes from the fact that physics has been tested in high-energy colliders to this distance and that no sign of their existence has been found. We will see that this has to be somewhat mitigated: high energy physics experiments use the electroweak and strong interactions to test particules. Thus, in the case where extra dimensions would be only accessible to gravitational interactions, the high energy limits do not apply [4]. Indeed, until recently gravity was only tested down to the millimiter range, which thus provides the limit for the size of extra dimensions in this case, a macroscopic scale!

Let us pause a second to get a closer look at the type of universe that would emerge in this case: since non-gravitational interactions (as well as matter) do not "feel" the extra dimension, this means that our ordinary world of quarks, leptons and gauge interactions is localised on a 4-dimensional surface[3] (described by 3 spatial and 1 time coordinate) which is plunged into the higher-dimensional universe. Such a surface is called a brane, or more precisely a 3-brane (3 spatial dimensions): the term brane obviously refers to a membrane (strictly speaking a 2-brane). Our observable world is therefore "glued" to the brane and only gravity can probe the higher-dimensional universe outside the brane. Such a set-up had already been encountered in the context of string theory from which the term *brane* is borrowed: there the branes appear as the surfaces described by the end of the open strings [5]. The extra dimensions then need not be finite in size since our senses, as well as our optical or electromagnetic devices, only test the 4 usual dimensions. In what follows, we will refer to such a set-up as a braneworld and talk of Kaluza-Klein extra dimensions in the case where they can be probed non-gravitationally.

How would one identify the existence of extra dimensions?

The first test that one could think of is to check how the gravitational force decreases with the distance. Indeed, the law of variation with the distance is obviously related to the dimensionality of space. Because a sphere in 3-dimensional space (4-dimensional spacetime) has a surface which varies as the radius squared, the distant effect of any point source (whether the water projected by a sprinkler, the electric force of a pointlike charge or the gravitational attraction of a mass) decreases with inverse distance squared. This is summarised by the famous law of gravitational attraction
between two masses m_1 and m_2 distant by r; $G_{(4)}$ is Newton's constant.

$$F(r) = G_{(4)}\ \frac{m_1 m_2}{r^2} \qquad (1)$$

A sphere in (3+D)-dimensional space ((4+D)-dimensional spacetime) has a surface which varies as its radius to the power 2+D; we thus expect a gravitational force which decreases as $r^{-(2+D)}$. This should in principle be enough to discard the possibility of extra dimensions.

However, one should be careful in the case of compact dimensions when the distance r is large compared with the size L of the compact dimension(s). Let us discuss first in more details what happens in the case of a single compact dimension. We modelise such a universe by the infinite torus of Figure 1 (a): the infinite dimension represents any of the 3 standard infinite dimensions that we observe, whereas a compact dimension is visualised by the circle of length $L = 2\pi R$. We consider two masses m_1 and m_2 separated by a distance r on this torus. A gravitational field line may join them directly, or may make one (or more) turns round the torus. Hence (see Figure 1 (b) where the torus is now represented by a series of strips with proper identification) the mass m_1 feels the effect of mass m_2 and all its *images*. If r is much larger than L then these images form a continuous line. In the case of D compact dimensions, one obtains a D-dimensional continuum of

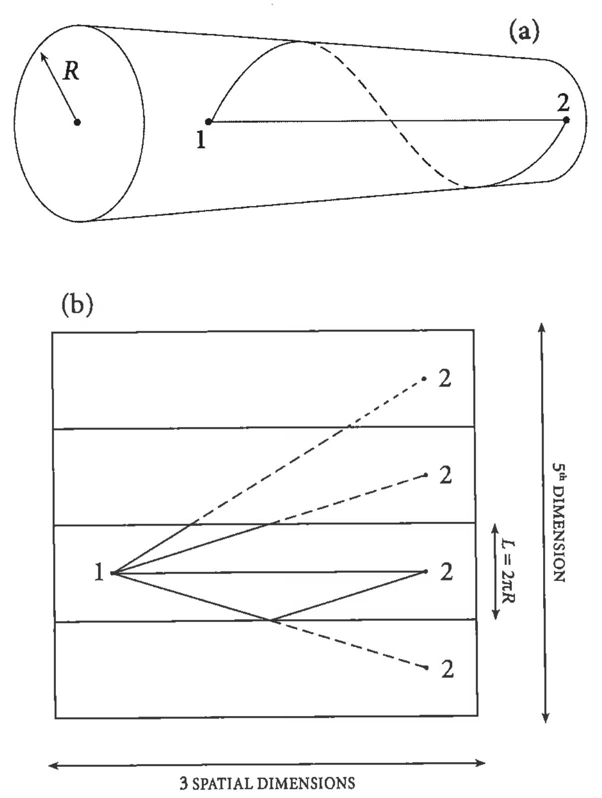

Fig. 1: (a) Infinite torus (b) Same torus represented by strips with opposite sides identified

masses. Then the gravitational force exerted by this continuum on m_1 reads

$$F(r) = G_{(4+D)} \frac{m_1 m_2}{r^2 L^D} \qquad (2)$$

which has the standard form (1) under the identification

$$G_{(4)} = \frac{G_{(4+D)}}{L^D}\,. \qquad (3)$$

Of course, when distances become of the order of or smaller than L, one recovers the law of higher-dimensional gravity in $r^{-(2+D)}$. Thus one still expects deviations from the standard law at small enough distances.

There is another way of identifying extra dimensions which leads to interesting signatures in particle physics. It rests on the fact that one (or more) compact dimension may be assimilated to a finite box. It is well-known that standing waves in a box have wavelengths λ such that the size $L \equiv 2\pi R$ of the box is a multiple of λ: the wave number k satisfies $k = 2\pi/\lambda = n/R, n \in Z$ and the energy is quantized: $E = \hbar c k$. We also expect the same phenomenon to occur in our higher-dimensional box. Since there is a duality at a fundamental level between particles and waves, we are expecting particles with a mass spectrum characteristic of standing waves, i.e. quantized in units of $1/R$. These oscillation modes are called Kaluza-Klein modes and they are actively searched for in high energy colliders.

Let us be a little more explicit in the case of a single extra dimension. The standard formula for the energy of a relativistic particle of 3-momentum p and mass m_0, $E^2 = \mathbf{p}^2 c^2 + m_0^2 c^4$, reads with a fifth dimension

$$E^2 = \mathbf{p}^2 c^2 + p_5^2 c^2 + m_0^2 c^4$$

where p_5 is the momentum in the fifth spacetime dimension, quantized as discussed above: $p_5 = \hbar k_5 = n\hbar/R$. Thus, in the centre of mass ($\mathbf{p} = 0$), one obtains the following energy spectrum:

$$E^2 = \left[m_0^2 + \frac{n^2 \hbar^2}{R^2 c^2} \right] c^4.$$

Hence, a 5-dimensional field is identified in 4 dimensions to a tower of particles regularly spaced in mass-squared, the mass gap being given by the inverse of the compact dimension size. This can be put differently: if the world is indeed 5-dimensional with a fifth dimension of finite size, one expects to find besides the electron a tower of electron-like states with exactly the same properties (spin, charge,...) except the mass: the first state lies in a mass range which is all the higher as the size of the fifth dimension is smaller. These are the Kaluza-Klein modes of the electron. Because of their characteristic spectrum, finding them would be a dramatic signature that we are living in a higher-dimensional universe.

What does experiment tell us at this point? Since no deviation from the law of gravitation has been observed and no Kaluza-Klein mode has been detected, we may only put limits on the size R of the extra dimensions. We have to consider two different cases:

- if the extra dimension is felt by non-gravitational interactions, that is if Kaluza-Klein modes have electromagnetic, strong or weak interactions, they could be found in high energy colliders[6]. Their non-observation at the highest energy presently observable gives a lower limit on their mass and an upper limit on R:

$$\frac{\hbar c}{R} > 1 \text{ TeV} \leftrightarrow R < \frac{\hbar c}{1 \text{ TeV}} \sim 10^{-4} \text{ fm}$$

- if Kaluza-Klein modes only have gravitational interactions, i.e. if we are in the braneworld set up briefly discussed above, their gravitational couplings are very small and they could easily have been missed (see however below). The only limit comes from the direct study of the law of gravitation; since it has been checked down to the millimiter range

$$R < 1 \text{ mm} \leftrightarrow \frac{\hbar c}{R} > 10^{-4} \text{ eV}.$$

Gravity and the other fundamental interactions

Gravity is the weakest of all known fundamental interactions. This can be rephrased in terms of energy scales typical of each interaction.

In the case of strong interactions, which hold together quarks in a proton, one may take as a representative scale the mass of the proton, 1 GeV/c^2: the quark masses are negligible and most of the proton mass is binding energy.

For electroweak interactions, one may take the mass of intermediate vector bosons which mediate weak interactions, typically 100 GeV/c^2. One could alternatively take the value of the scalar field in the vacuum, around 250 GeV.

Gravity is characterised by a dimensionful coupling: $G_{(4)} = 6.673 \times 10^{-11}$ m^3.kg^{-1}.s^{-2}. One may turn this into a mass scale if one uses the Planck constant $\hbar$ and the speed of light c. This is the Planck mass:

$$M_{Pl} \equiv \sqrt{\frac{\hbar c}{G_{(4)}}} \sim 1.22 \times 10^{19}\ \mathrm{GeV}/c^2 \qquad (4)$$

(around 10^{-8} kg). The presence of the Planck constant indicates that the Planck scale gives the energy scale where *quantum* effects start being important in gravity.

There are therefore some 17 orders of magnitude between the fundamental scale of gravity and those of all known gauge interactions. This induces some delicate problems of fine-tuning when one considers the effect of gravity quantum fluctuations on standard "low energy" parameters (in particular the Higgs particle mass).

Extra dimensions may bring a new twist to this question. Indeed, one should take as the fundamental coupling describing gravitational interactions the higher dimensional Newton's constant $G_{(4+D)}$, not the 4-dimensional one $G_{(4)}$. One may turn this higher-dimensional coupling into a fundamental mass scale M_f, just as in (4):

$$G_{(4+D)} \equiv \frac{(\hbar c)^{D+1}}{c^{2D} M_f^{D+2}}.$$

Then (3) gives

$$M_{Pl}^2 = M_f^{D+2}\left(\frac{Lc}{\hbar}\right)^D$$

Thus, the larger the compact dimension is, the smaller the fundamental scale could be. For example, $D = 2$ millimetre size dimensions would give a scale M_f in the TeV ballpark. How would this be detected experimentally?

Experimental determination of the size of compact dimensions

In very high energy proton-proton collisions, such as at the future CERN Large Hadron Collider (LHC), the constituents of the protons (quarks and gluons) collide. A possible final state is made of a quark and a graviton: the quark hadronizes into a jet of particles and the graviton escapes into the extra dimensions. Thus the signature is a jet plus missing energy. If M_f is in the TeV range, the signal due to extra dimensions may overcome the Standard Model background for large transverse jet energy.

One issue which has been discussed at length recently is the exciting possibility of producing microscopic black holes at colliders, in the case where dimensions are large enough to allow the fundamental higher-dimensional gravity scale M_f to be in the TeV range.

On the side of astrophysics, a strong constraint comes from supernovae. After a supernova explosion, cooling occurs by release of energy mainly through neutrinos and gravitational waves. If higher dimensions are probed by gravity, more phase space is accessible to gravitational waves and cooling is enhanced. This puts lower limits on M_f typically in the 50 TeV range, which, in the simplest models, does not favour experimental signatures at colliders.

Finally, a large effort is invested in trying to improve limits on the validity of the law of gravitation. Sophisticated systems have been conceived to try to reach a limit of a few microns [7]. One of the problems is to disentangle a novel effect due to extra dimensions from the Casimir effect due to quantum fluctuations in the region between the two test masses.

Cosmology of the brane world

Besides shooting gravitons at the extra dimensions using powerful high energy colliders, there is a priori a quieter way of testing these extra dimensions which is looking at the stars and observing the evolution of our own Universe. Indeed, since gravity is changed in a drastic way (number of space dimensions), one may expect that the cosmological evolution of the Universe is changed.

Let us consider a toy model of a 4-dimensional brane universe plunged into a 5-dimensional universe; matter and gauge interactions (and thus galaxies, photons and so on) are localised on the brane, whereas the full fifth dimension (the *bulk*) is accessible only to gravitons (see Figure 2).

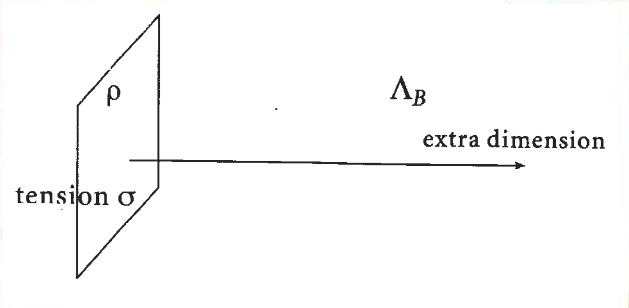

Fig. 2: Brane world set up with a single extra dimension

We are certainly used to the fact that our Universe is curved, at least locally by any gravitational field produced by a mass. This is the notion of intrinsic curvature, which can be "observed" by parallel transporting a vector along a closed curve and checking that it has changed once it has returned to its starting position. But there is also the notion of extrinsic curvature which corresponds to our naive understanding of "curved": the way a sheet of paper is bent for example. There is therefore a fundamental difference between a 4-dimensional universe and a 4-dimensional brane universe plunged into a 5-dimensional one: in the latter case, the way the brane universe is "bent" inside the bulk has some physical consequences.

One of them is of cosmological nature. The rate of expansion of the universe is measured by the Hubble parameter H. In a standard 4-dimensional universe, H^2 varies linearly with the total energy density ρ: this is the Friedmann equation. It follows that, in a radiation-dominated universe, such as our own at the time of nucleosynthesis, the cosmic scale factor (which measures the expansion of distances in the Universe) varies with time as $t^{1/2}$. In the 4-dimensional brane universe plunged in a higher-dimensional bulk that we consider, H^2 varies as ρ^2, the *square* of the energy density on the brane [8]. This would give a slower expansion (cosmic scale factor varying as $t^{1/4}$ in a radiation-dominated universe), in contradiction with was is observed from nucleosynthesis onwards. The solution is to have a constant piece in the brane energy density: this vacuum energy is interpreted as the tension σ of the brane. Then H^2 is proportional to $(\sigma + \rho)^2$: the energy density decreases with time and at late time, r being small, one recovers a linear behaviour in ρ. On the other hand, the ρ^2 term is important in the very primordial universe.

An important issue is the one of the cosmological constant. It is well-known in 4 dimensions that this constant is nothing but the vacuum energy: this is the source of the notorious cosmological problem: this vacuum energy is expected to be of the order of the fundamental scales in the microscopic theory, and this exceeds the observational constraint by many orders of magnitude.

In the brane set up that we consider, the cosmological constant λ observed on the brane receives two contributions: as we just saw, one quadratic in the brane tension (i.e. brane vacuum energy), and one linear in the 5-dimensional bulk vacuum energy Λ_B:

$$\lambda = \frac{\sigma^2}{36\, M_f^2} + \frac{\Lambda_B}{6\, M_f^3} \quad .$$

A vanishing (or very small) cosmological constant thus requires an adjustment of the two vacuum energies: this is the standard fine tuning problem. If we allow for such a fine tuning, we are in for a big bonus: we may allow the extra dimension to be infinite. Indeed, if the brane tension is positive[4], one finds a solution of the Einstein equations for which the 5-dimensional geometry is "warped". And this solution has the following property: among the Kaluza-Klein modes of the 5-dimensional graviton, there is a massless mode which is localised on the brane [9]. It is interpreted as the 4-dimensional graviton. Because of the localisation, 4-dimensional gravity becomes rapidly negligible as one goes away from the brane. It must be said that, even though the extra dimension is infinite, its volume remains finite because of the warped geometry. This model, the Randall-Sundrum model [10], has generated a flurry of activity in the last couple of years.

Of course, many other aspects of the cosmology of such brane worlds have been investigated and it goes beyond the scope of this article to review them. Let us just mention the activity going on in order to obtain definite predictions for the fluctuations in the cosmic microwave background. The difficulty comes here from the fact that the 4-dimensional brane does not form a closed system: it is for example subject to bulk mode excitations, such as gravitational waves.

It remains to be seen whether this general new perspective will provide us with solutions to long standing problems. One may lose some of the successes of the standard 4-dimensional approach, for example gauge coupling unification (more accurately, unification appears more contrived in higher-dimensional models) or some of its guiding principles (renormalisability). It is thus important to see what one gains in the long run. At this point, extra dimensions provide the ground for exciting new ideas which are (or should be) substantiated by a consistent quantum framework, string theory. A complementary approach between high energy physics, astrophysics and cosmology should provide us with some ways to test experimentally these ideas.

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Footnotes

1 with precursors such as H. Weyl and G. Nordström.

2 More precisely, the one-dimensional string covers in its motion a 2-dimensional surface, the world-sheet. String theory can be described as a theory on this 2-dimensional surface: if s labels points of the string and t time, then the position of any string point in spacetime is $x\mu(s, t)$; each coordinate $x\mu$ may thus be understood as a field on the worldsheet. This is why the dimensionality of spacetime, i.e. the number of such coordinates, plays a key role.

3 or a set of such surfaces.

4 as is probably required by stability requirements.

Offshore wind technology ready for application

Maarten van der Sanden , Delft University of Technology

The technology for the construction and operation of offshore windfarms is ready for large-scale application. Companies in the fields of engineering and services are preparing to take part. This can be seen in the conclusions of the project Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) of the European Union, in which seventeen parties from thirteen European countries have brought together knowledge on this subject from all over Europe. The Wind Energy section at TU Delft, which co-ordinated the project, has published a final report on the internet: www.offshorewindenergy.org.

The project Concerted Action on Offshore Wind Energy in Europe (CA-OWEE), was funded by the European Commission to stimulate the development of offshore wind-energy into an important energy source. Now that the technology is viable, the most important challenges lie in the reduction of costs, the building up of experience and confidence in the building and maintenance of large wind-parks, the connection of these parks to existing electricity networks and the consequences for the landscape and birds. The authors make suggestions for where further research should be focused.

The European Commission's project was focused on large-scale exploitation of offshore wind by wind-turbines with a large capacity and high scores for performance, sustainability, availability and reliability. The EU would like wind-turbines that are friendlier for the environment and for which the costs of installation and production are lower than that of current units.

Currently, the largest European offshore wind-turbine park is that at Middelgrunden, several kilometres off the Copenhagen shoreline, in Denmark, with a capacity of 40 MW. This year in Horns Rev, on the western coast of Denmark, a park with a 160 MW capacity will be built and a 100 MW wind-park is planned for construction next year at Egmond off the Dutch coast along with many other locations across Europe. Experts expect that by the end of this decade wind-parks will be built at sea with a total capacity of thousands of megawatts, comparable to that of several coal-fuelled power plants and enough to supply millions of homes. Sweden, Denmark, Germany the Netherlands, Belgium, Great Britain and Ireland have advanced plans for such parks on their shores.

In the project Concerted Action on Offshore Wind Energy in Europe, partners from many fields worked together: a public utility, windfarm developers, advisors, research institutes, universities, consultants, an offshore engineering company and a certification body; this is reflected in the broad range of subjects examined.

features

EPS–12: Trends in Physics

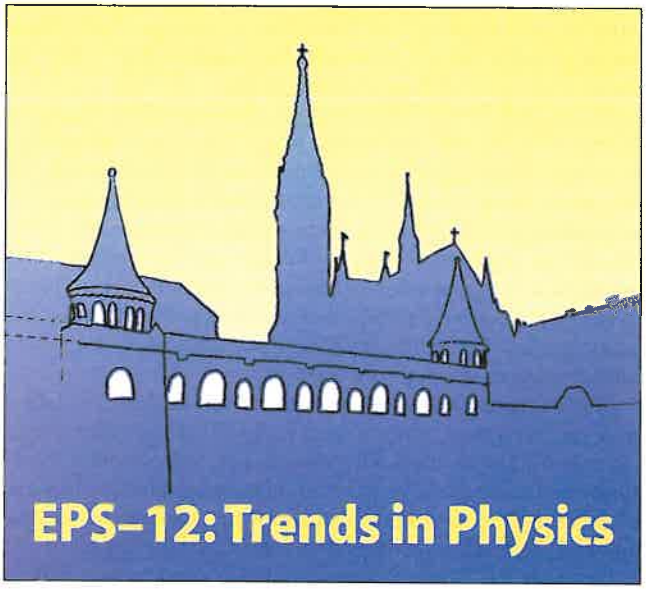
12th General Conference of the European Physical Society

The first meeting of this triennial series in the new Millennium will bring together scientists and teachers from different fields of physics from Europe and around the world.

The conference venue will be the Physics Building of the Eotvos University situated along the banks of the Danube river at one of the most picturesque parts of the Hungarian capital.

The programme of EPS-12 will follow the traditional scheme of the series consisting of plenary talks, parallel symposia and posters. Speakers of the plenary talks have been invited by the International Programme Committee and the list of confirmed Plenary Speakers is available at the conference web site. Speakers of the parallel symposia have been or are being invited by the Conveners; the programme of the symposia will be regularly updated at the conference web site.

Many exciting plenary lectures are scheduled, including Z. Alferov, (Semiconductor Heterostructures: State-of-Art and Future Trends); F. Close, (A picture of the week is worth a thousand words); L. Hau, (Slow Light); H. Nifenecker, (How much could nuclear power contribute to the mitigation of CO2 emissions?) and L. László, (Eugen Wigner Memorial Lecture: Remembering Eugene Wigner, Pondering his Legacy)



Budapest, Hungary (26-30 August 2002)

http://www.eps12.kfki.hu/

Parallel symposia are also planned, which will be organised by EPS Divisions and Interdivisional Groups covering the latest developments in physics in their fields.Topics include Computational Physics: Interdisciplinary Applications; European Research Infrastructure (Neutron and Photon Sources, Low-Energy Ion Accelerators); Nanostructures; and Physics in Biology.

It is envisaged that most plenary events of EPS-12 will be in real time web-casted on the Internet with some possibility of feed-back from the 'virtual audience'. One of the highlights of this action will be the Round Table Discussion on the future and the social role of science, especially physics. Participants of the Round Table Discussion will be distinguished scientists as well as leading European science policy makers. We expect a lively interaction between participants of the Round Table and the audience. The Round Table will take place on Tuesday, 27 August in the evening.

EPS-12 and ICPS 2002, the 17th International Conference of Physics Students, are being organised in a close collaboration between the organising bodies of both conferences. Indeed, IAPS, the International Association of Physics Students is organising its annual conference, ICPS 2002 at the same venue from 21 to 27 August. The first two days of EPS–12, 26 and 27 August represent a full overlap between the two events with joint programme on those two days.

The successful tradition of the Young Physicists' Poster Competition and the Young Physicists' Day will be continued, this latter plenary session taking place on Tuesday, 27 August in the morning, i.e., as part of both conferences.

Abstract Submission Deadline

Abstracts for poster presentation can be submitted through the registration and abstract submission pages of the web site from 1 March to 5 April 2002. High-level abstracts will be accepted from all fields of physics or physics teaching up to one abstract per registered participant.

Fees and Support

The registration fee, if paid before 14 June, will be 260 Euros for EPS National Society Members and 130 Euros for students.

For further special and/or late registration fees please visit the conference web site.

Prospective young participants, younger than 35 years of age at the time of the conference may apply for grants, which could be used towards the registration fee, and/or hotel accommodation and/or travel costs, depending on the available level of individual supports. For details on these conditions please consult the respective links at the EPS-12 home page. The Organising Committee of EPS-12 will decide on the grants. Preference will be given to those participants who make poster presentation on the joint day of EPS-12 and ICPS 2002 and intend to take part in the Young Physicists' Poster Competition.

Request for financial support can be submitted to the Organising Committee when filling in the final registration form, but not later than 5 April 2002.

The applicant must provide a supporting letter from the Head of the Department where his/her work has been carried out. This letter is to be sent by surface mail or fax to the EPS-12 Conference Secretariat until 5 April 2002.

Journal de Physique IV

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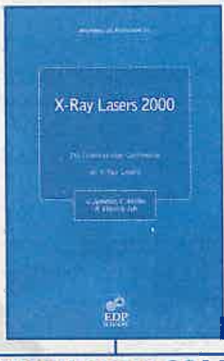


X-Ray Lasers 2000
7th International Conference on X-Ray Lasers

G. Jamelot, C. Möller, A. Klisnick, Eds.
Saint-Malo, France, June 19-23, 2000

'his volume contains the invited and contributed apers presented at the Seventh International Conference on X-Ray Lasers. It provides not only n overview and an up-to-date progress report on his fast moving field, but also important reference naterial on which future work can be built. Topics overed include: transient collisional excitation X-ray asers, capillary discharge-pumped X-ray lasers, OFI X-ray lasers, other collisional X-ray lasers, other outes to X-ray and γ-ray lasers, theory for X-ray asers and modeling of amplified beams, high-order armonics X-UV radiation and other high brightness -ray sources, applications of X-ray lasers and other bright X-ray sources, X-UV optics and nstrumentation, investiations on X-ray laser media, nd development of X-ray laser drivers.

2001 • 2-86883-548-1 • **150 €**

EUROCVD 13
Thirteenth European Conference on Chemical Vapor Deposition

D. Davazoglou, C. Vahlas, Eds.
Glyfada, Athens, Greece, August 26-31, 2001

The present volume contains the proceedings of the 13th European Conference on Chemical Vapor Deposition (EUROCVD 13). CVD is one of the major techniques for the fabrication of micro- and nano-scale films, tubes, and particles. Enhanced implementation of CVD in actual and forthcoming advanced industrial processes will depend on the comprehension, control, and optimization of the "processing conditions - deposit microstructure (morphology, composition) - material performance" relations. EUROCVD 13 was recognized by the European Commission as a High Level Scientific Conference which meets clearly identified needs, such as: i) deeper insight into the fundamental phenomena which control the above correlation; ii) identification of the materials issues where CVD can be used, scale up of the process, and co-ordination among chemical suppliers, equipment designers, software developers, and end-users; iii) contribution to the improvement of the quality of life (as a consequence of enhanced performance of the materials produced), through the developments in fields such as microelectronics, energy storage, or hard and protective coatings; iv) teaching and training of young researchers on the multiple aspects of CVD, and their interactions with the specialists in these fields.

2001 • 2-86883-549-X • **190 €**

EUROMECH-MECAMAT'2000
4th European Mechanics of Materials Conference on Processes, Microstructures and Mechanical Properties

E. Aeby-Gautier, M. Clavel, F. Dunne, Eds.
Metz, France, 26-29 June, 2000

The optimisation of product manufacture requires considerable knowledge of the interactions between process, microstructure and mechanical properties. The improvement of microstructure-related mechanical properties, and the development of new materials, requires further studies of process development, microstructure evolution during manufacturing processing and the relationships between processing route, microstructural evolution, and resulting mechanical properties. This conference focussed on experimental, modelling and numerical aspects concerned with the relationships between processes, microstructures, and mechanical properties of solids. The coupling between process, microstructure and final properties, and the material behaviour for processes where a coupling exists between mechanics and microstructural evolution, were considered. Attention was also paid to new processes and new materials.

2001 • 2-86883-550-3 • **95 €**

ESOMAT 2000
Fifth European Symposium on Martensitic Transformations and Shape Memory Alloys

G. Airoldi, S. Besseghini, Eds.
Villa Olmo, Como, Italy, September 4-8, 2000

The volume contains the Proceedings of ESOMAT 2000, held on 4-8 September, 2000, Como, Italy. Scientific sessions include fundamental aspects and physical properties of martensitic transformations in Cu-based, Fe-based alloys, martensites and magnetoelastic phenomena in NiMnGa, shape memory properties in NiTi and NiTiCu alloys, shape memory thin films and high temperature alloys, composites and applications of shape memory alloys.

2001 • 2-86883-565-1 • **150 €**

TFDOM 2
International Conference on Thin Film Deposition of Oxide Multilayers Hybrid Structures

J. Kreisel, C. Dubourdieu, Eds.
Autrans, France, October 18-19, 2001

This conference was organized in the frame of the European Community FP5 Program, within the "MULTIMETOX" thematic network. The main scope of this Conference was to provide an up-to-date and comprehensive overview of research and development including, basic physics, material science, with a special focus on application of superconducting, ferroelectric and magnetoresistive oxide thin films and multilayers in electronic devices. The Conference focussed on the following general topics: ferroelectric and dielectric oxides, high temperature superconductors, magnetic oxides, thin films and multilayers, epitaxial growth and related problems, microstructure and physical characterizations, applications of metal oxide multilayers.

2001 • 2-86883-573-2 • **88.50 €**

EPS becomes partner in exciting European education project

Silvia Merlino, Roberto Fieschi, Marco Bianucci and Brian Davies

New multimedia technologies have shown their potential for providing significant steps forward both in the teaching of scientific and technological subjects, and in popularising them. In comparison with other subjects, physics and technology are often considered difficult, but interactive multimedia tools, with their simulations and video clips can be very effective for giving good preliminary intuitive approaches to scientific concepts.

In its Report, the Educational Software and Multimedia Task Force concluded that while the European demand for educational software is steadily increasing, the offer of quality products is still limited. In particular, there is a lack of products aimed at young students and people of limited educational attainment; there is a clear need to diffuse good quality educational products across national frontiers.

The spread of computers and the Internet facilitates the use of multimedia products as a support for teaching, for raising public awareness of science and technology and for bridging the gap between science and technological achievements on the one hand and the general public on the other hand, in an accessible way.

These considerations encouraged us to initiate the project Multimedia on Energy and Semiconductors for European Countries , which has been selected by the Commission of the E.U. within its Raising Public Awareness programme.

The specific objective is to provide young students, their teachers and the general public in European countries with a courses on Energy and its transformations , and on Semiconductors and their applications in the form of user-friendly multimedia packages both on the Internet and on CD-ROMs, for both PC and Mac platforms.

The starting points are the multimedia courses L energia e le sue trasformazioni and Dal Silicio al Computer , produced by the Istituto Nazionale per la Fisica della Materiale (INFM) with the financial support of the Ministero della Pubblica Istruzione (with the supervision of Inspector G. Marucci) and of the Ministero della Ricerca Scientifica e Tecnologica (MURST). These Italian versions are on CD-ROM and on line at:
http://multimedia.infm.it/energia,
http://multimedia.infm.it/dsac.

In developing these courses, we kept in mind the need to capture the attention, and then encourage the interest of the student, or member of the public. If diffidence and lack of confidence can be overcome, then physics, chemistry and technology become interesting and fascinating subjects. In order to be able to convey their charm, we paid a lot of attention to finding simple, straightforward ways to introduce concepts. We often start from everyday phenomena, and then we show the underlying science. Much use is made of animations and interactivity and, where possible, simulations. A lot of attention has also been paid to the production of attractive graphics. Throughout, everything must, of course, remain scientifically rigorous. Moreover, we include several sections for consolidating ideas, and numerous historical notes and curiosities to stimulate interest in historical aspects of science. We provide a long list of suggested experiments, all of which can be easily done at home or in the classroom. For the younger students, in particular, we provide interactive games that are amusing but at the same time provide summaries and reviews of the whole subject.

The project team involves INFM as coordinator and 4 European partners:

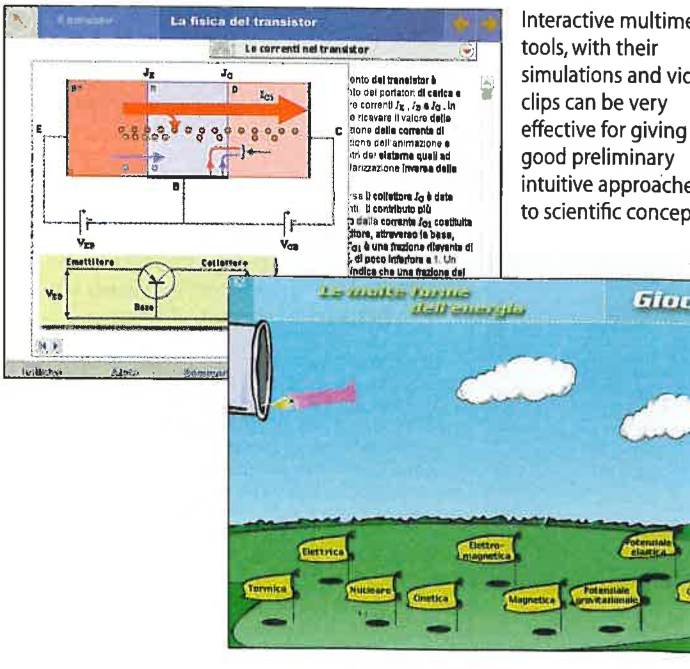
- **Sciencewords** (Consultancy), Mr. Brian Davies, U.K.;
- **Ediciones del Laberinto**, Dr. Juan Josè Ortega, Spain;
- **The European Physical Society**, Mr. David Lee [based in France];
- **INFMedia Srl**, Dr. Oreste Tommasi, Italy.

The participating organisations were chosen for their established skills and competence to deliver the entire project.

INFM is the co-ordinator of the consortium. This Institution coordinates and supports research on the Structure of Matter in Italian universities. Traditionally, this kind of Institution is only involved in research at an advanced level, and is not involved in problems of pre-university teaching or the popularisation of science. However, during the last few years, INFM has included these issues among its objectives, aware of the fact that researchers need to be more open to, and involved in, the problems of the society; scientists can no longer stay in their ivory towers.

Sciencewords is a consultancy with proven expertise in physics and physics education, history of science, writing and editing, the cross-cultural influences of science and in public awareness of science programmes.

Ediciones del Laberinto is involved in 6 000 educational centres in Spain and is well equipped for the promotion and the distribution to the Spanish Schools.



Interactive multime tools, with their simulations and vic clips can be very effective for giving good preliminary intuitive approache to scientific concep

INFMEDIA Srl is a small company devoted to the design and realization of interactive multimedia software for the diffusion of scientific knowledge, teaching support and technical training.

EPS: the European Physical Society does not need a description here!

The main steps for each of the two multimedia packages are:

- the translations from Italian into English and Spanish.
- the implementation of the multimedia formats.
- the production of English and Spanish prototype versions of the CDs and web-sites in time for the European S&T Week 2002.
- the distribution of CD prototypes for trials in schools in England and in Spain, during 2002-2003
- production of final English and Spanish CD and web versions of the multimedia packages for wider distribution, taking into account the ideas and suggestions from the schools.

We hope that our work will contribute to the general objectives of raising public awareness of science and technology by explaining something of the impact of science, its applications and its benefits. We also hope that it will help to improve human research potential, particularly in a period when, in most European countries, there is a considerable difficulty in attracting young people to scientific careers.

Both the European Science and Technology Week in November 2002 and the European Physical Society s network support, which will continue into 2003, will provide excellent opportunities for a widespread introduction of these educational products to the general public.

Brief bibliography of related materials

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ARCHIMEDES, Multimedia on- line archive on Science and Technology in Italy: http://multimedia.infm.it/archimedes. Scientific Committee: R. Fieschi, S. Fantoni, A. Pascolini, M. Bianucci, V. Marchis, P. Galluzzi, O. Tommasi; Comitato di redazione: M. Bianucci, P. Chessa, S. Merlino.

R.Fieschi, R.Roncaglia: Technet Dal Silicio al Computer , multimedia course on line, on Silicon and its application, published on http://multimedia.infm.it/dsac.

R. Fieschi, M. Bianucci: L energia e le sue Trasformazioni : Multimedia on-line course, on-line on Energy and its Transformations,

R. Fieschi, M. Bianucci, S.Merlino: Proprietà Dei Materiali : interactive course on CD-ROM, for undergraduate students.

Brian Davies and Andrew Millington (Omni Productions): Inspired by Nature, a 40-minute videotape as part of the Learning from Nature video/TV. and web-site programme for European Science and Technology Week, 2000. [Related articles: Learning from Nature European Physical Society News, Sept/Oct 2000, and Nature, a breeding ground for science , RDT Info, Jan 2001]

Brian Davies: Physics like you've never had before , Physics Education, March 1998 .

About the authors

Silvia Merlino—Researcher of INFM in the Physics Dep. of Parma University, was educated as an astrophysicist. Now engaged in public awareness of science activities and the creation of new media products dealing with physics and technology. merlino@fis.unipr.it

Roberto Fieschi—Professor of Physics of the Matter in the Physics Dep. of Parma University, has worked for many years on solid state physics. Now he is involved in the production of multimedia for the teaching of physics and technology. fieschi@fis.unipr.it

Marco Bianucci—INFM Researcher in the Physics Dep. of Parma University, has worked on statistical physics. Now engaged in public awareness on science activities and has produced multimedia products on physics and technological subjects. bianucci@unipr.it

Brian Davies—formerly: director, education and public affairs, Institute of Physics; university teacher of physics, history of science, physics education. Established Sciencewords consultancy, 1998: writing, public lectures on physics and fine art, European programmes for schools and the general public. brian.davies@sciencewords.demon.co.uk

From leprechauns to lasers?

Ireland's sustained economic growth has transformed its society and culture in many ways. In the latest development, a dramatic new programme has been announced, aimed at sustaining a knowledge-based economy. This requires a high level of research and development, and a culture of scientific and technological innovation. While Ireland's scientists have been to the fore in building scientific networks in Europe, at home they have long suffered from inadequate funding. Now, in the boldest move since the Dublin Institute of Advanced Studies was established in the thirties, a new funding body has been established by the deputy prime minister, Mary Harney,and the minister for science, Noel Treacey. Its budget is far from miserly - over six hundred million euros for five years. Already it has made substantial awards to researchers in information and communication technology and biotechnology, its prime target areas. Among the successful applicants several are physicists, for example John Pethica, who will move from Oxford to Trinity College Dublin. and Eoin O'Reilly, who moves from the University of Surrey to the National University of Ireland, Cork.

Dr William Harris with Mary Harney and Noel Treacey, members of the Irish giverenment responsible for the new initiative.

The new agency, Science Foundation Ireland, is headed Dr. William C. Harris as Director-General, together with a board that includes Bob Laughlin, the 1998 Nobel Prize winner in physics, and Denis Weaire, former President of the EPS.

The initial grants were of the order of five million euros for each project, for five years. There is an open call for further internationally competitive research projects. In addition, funding will be available for the ongoing research of groups already based in Ireland, together with conference and distinguished visitor funding, and the support of centres for collaboration with industry. The visiting awards will commemorate Ernest Walton. It's a phase transition, says Denis Weaire, and it ain't second order!

Waiting for the Euro

Peter Richmond[1] and Lorenzo Sabatelli[1,2]
[1] Department of Physics, Trinity College Dublin, Ireland
[2] Hibernian Investment Managers, IFSC, Dublin, Ireland

Many feel that finance is a rough sea. For the British, sailing is a well-established skill. Today London is unquestionably the financial Capital of Europe, even if (or, maybe, also because of this?) it lies outside the Euro-zone. So what could be a better place than London to celebrate APFA3; just a few days before the launch of the new European currency.

January 1, 2002 – lift off day for the Euro and an auspicious day on which to reflect on the 3rd EPS conference entitled 'Application of Physics to Financial Analysis. Following previous meetings in Dublin and Liege, APFA3 was held in London from December 5th–7th. Events of September 11th caused some concern, as did other competitive events that were organised during the December period. In the event, around 100 researchers from across the world attended the meeting that was held in the Museum of London. Chosen for its proximity to the City of London and trading centres, this proved to be an excellent venue having a very good and well-equipped lecture theatre and auxiliary rooms for the extensive poster presentations. The museum itself proved to be an added bonus. Overlooking the River Thames, this gave participants a unique view of London and included the new *London Eye*.

Taking part in the conference we had the impression that, whilst the relation between physics and applied finance may be still at the embryo stage, this embryo is evolving very quickly. As with nature, a sign of evolution is the emergence of different and specialised branches, each with their own specialised character.

Empirical analysis of financial markets has been a particularly fruitful field of study in the last few years. Methods originally devised for analysing complex physical systems have been successfully applied to study the main statistical properties of financial time series. M. Ausloos and K. Ivanova presented an interesting analysis of EU currencies exchange rates using detrended fluctuation analysis. They showed that, in spite of being outside the Euro system, the British Pound has behaved, from a statistical point of view, very much like the main Euro currencies (French Franc and German Mark). Even if this finding does not bring to an end the debate about entry of the UK to the Euro, it could offer a more objective platform for further debate. Also of interest was the application of wavelet-based techniques by E. Copabianco to estimate volatility processes. F. Michael also presented a novel and interesting application of non-extensive Tsallis statistics to the analysis of intra-day price changes in the S&P500 stock index.

When analysing markets price and price changes, and time lags between two consecutive transactions show very interesting stochastic properties. Some interesting results on these 'waiting times distributions' for the Irish stock market of XIX century and modern Japanese currency market were presented by S. Richmond and co-workers.

All these methods allow a 'kinematic' description. The most challenging issue is the dynamical description of microscopic processes that leads to the macroscopic phenomenology. S. Solomon showed how far this could be done using a generalised version of Lotka Volterra (GLV) equations J.P. Bouchaud discussed how an agent-based approach is able to unveil the microscopic mechanism responsible for statistical "anomalies" observed in time series and can offer a valuable contribution to risk assessment.

In financial markets, as for turbulent fluids, a key aspect is the relation between different scales and, in particular, on the existence of "continuous cascades" from coarse to fine scales. Muzy showed how, within a class of continuous multifractal random walks, stochastic volatility can result. Kholodnyi presented an interesting paper based on beliefs-preferences gauge symmetry. This showed that randomness in the prices of underlying securities can be formalised via non-commutativity of linear operators in the manner of quantum mechanics. A. Proykova and D. Stauffer presented an interesting approach to financial dynamics that invoked generalised non-equilibrium phase transition models..

Understanding how and why financial markets behave as they do is of primary importance for risks assessment and portfolio theory. J.P. Bouchaud's work is clearly leading to improvements and stimulating further research in this field. A number of posters developed this theme.

Increasingly there is a general and systematic adoption of Levy, as opposed to Gaussian statistics by the financial industry for both evaluation of risks and the pricing of derivatives. However it was clear from the discussion that many respected financial advisors still rely on technical indicators such as Fibonacci numbers and at times can appear closer to astrology than to science!

P. Ormerod used random matrix theory to show that for 10,000 individual properties in the UK, correlations between different types and geographical locations are more stable over time than stock market data. This is an interesting, and arguably surprising, result that suggests maybe government policy is not as important as people might have thought.

We see in this a good example of transfer of knowledge and know-how from academic environment to industry.

Of course physicists may still try to stretch some well known models to fit market behaviour, even when those models are based upon assumptions only plausible for some physical systems. Equally some financial practitioners continue to work with their usual traditional tools and look at physics as a marketing tool. Nevertheless, APFA3 closed on a positive note. There was a feeling that links between academe and the industry are healthy and that the new interactions between Physics and Finance are producing valuable scientific and economic results.

Closing the conference it was agreed that the venue for the next congress would be Warsaw in 2003, by which time; the subject should be truly a more mature physics topic. Whether, by then, the GBP will have truly merged with the EUR seems unlikely. Would you like to put a bet on that?

noticeboard

EPS general meeting

The general meeting of the European Physical Society will take place on Wednesday 28 August beginning at 12:00 at the Eötvös University, Physics Building, Pázmány Péter Sétány 1/A, 1117 in Budapest, Hungary. All members of the European Physical Society are invited to attend (that includes Individual Ordinary Members, National Society Members, National Societies and Associate Members). The preliminary agenda will be the President's report, the Treasurer's report and the Secretary's report.

Winners of the 2002 Accelerator Prizes

awarded by the European Physical Society Interdivisional Group on Accelerators (EPS-IGA)

Following the meeting of the EPS-IGA 2002 Prize Selection Committee chaired by Dr. Ferdinand Willeke of DESY on 20 February 2002, the 2002 Accelerator Prizes are awarded as follows.

The Prize for an individual in the early part of his or her career, having made a recent significant, original contribution to the accelerator field, is awarded to **Frank Zimmermann**, (CERN) *for his many important contributions to accelerator physics. In particular, he contributed significantly to the understanding of fast ion and electron cloud instabilities, the results of which have greatly benefited the whole accelerator community.*

The prize for an individual for outstanding work in the accelerator field is awarded to **Kurt Hübner**, (CERN) *for his excellent leadership in the field of accelerator physics and technology. He has provided guidance for generations of accelerator physicists and engineers, thereby contributing immensely to the prosperity of accelerators at CERN and many other laboratories around the world.*

The prizes will be awarded and the award winners will make oral presentations of their work during the 8th European Particle Accelerator Conference, EPAC'02, on 6 June 2002 at the La Villette Conference Centre, Cité des Sciences & de l'Industrie, Paris

Useful Links

EPS-IGA Home Page:
http://epac.web.cern.ch/EPAC/EPS-IGA/
Announcement of 2002 Prize Winners:
http://epac.web.cern.ch/EPAC/EPS-IGA/Accelerator_Prizes/2002_Laureates.htm
Past Winners EPS-IGA Prizes:
http://epac.web.cern.ch/EPAC/EPS-IGA/Accelerator_Prizes/EPS-IGA_Prize_Winners.htm
EPAC'02 Conference Home Page:
http://epac2002.lal.in2p3.fr/
Scientific Programme Pages:
http://epac.web.cern.ch/EPAC/Paris/Sci_Prog/

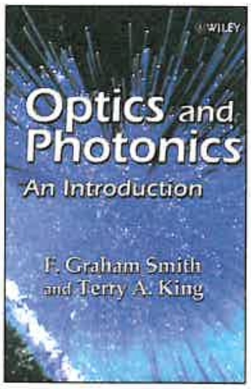
HEPP Outreach prize

Nominations are open for the EPS HEPP Outreach Prize. The prize is intended for outstanding outreach achievement related to High Energy Physics and/or Particle Astrophysics. The prize can be attributed to a scientist or to a non-scientist. It consists of a diploma specifying the work of the recipients, as well as a prize of 2000 CHF. The prize of this year will be given at the 12th General EPS Conference (Trends in Physics) 26–30 August 2002 in Budapest. Nominations should be sent to Jorma Tuominiemi (Jorma.Tuominiemi@cern.ch). The deadline for receiving nominations is until 15 May 2002.

IoP names its next Chief Executive

Julia King of Rolls-Royce has been appointed as the next chief executive of the Institute of Physics. Currently director of marine engineering and technology at Roll-Royce, King has strong links with both academia and industry, and takes a keen interest in science education. She will succeed current boss Alun Jones in September.

BOOK REVIEWS



Optics and Photonics: An Introduction

F. Graham Smith and Terry A. King
John Wiley & Sons, Ltd., 2000
456 pages

Writing a contemporary text dealing with optics is not an easy task as a manifold of choices have to be made. *Optics and Photonics: An Introduction* by F. Graham Smith and Terry A. King is an attempt to "propose and prove the properties of light by Reason and Experiments", as the authors quote Isaac Newton right at the start of their volume. The task they have put before themselves is a very hard one indeed.

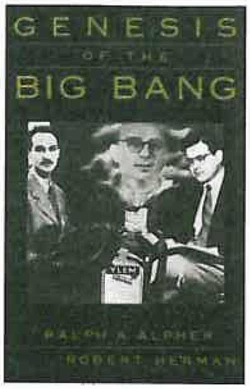
The book can be divided into two parts. The first 13 chapters may be considered "classical" material in optics and from chapter 14 onwards the photonics nature of light becomes more and more an integral part of the entire discussion. Each and every chapter of this volume is well written, with a clear focus on the important points made in text and equation. The authors make very good use of clear and abundant illustrations. It is a pleasure to go through a physics book with diagrams, graphs and pictures on almost every page. On the whole, the material is well presented, explanations are clear and order of magnitude indications of effects, lengths and sizes are given whenever this is useful. Every chapter comes along with a set of problems and numerical examples that are to the point and will aid the student very much in studying the material independently and get a good grasp of the orders of magnitude involved in the various processes.

The total of 22 chapters, each of them important and worthwhile, nonetheless constitute more material than a typical undergraduate semester-course in optics could contain, time wise. Since many of the topics that fascinate students the most, such as lasers, fibre optics and holography come near the end of the book it would have been nice of the authors would have included suggestions for "short cuts" in the material. I realise, of course, that choosing the order of chapters is partially determined by the hierarchy of knowledge presupposed in the topics treated in different sections and partially a matter of taste. But as the diverging interests of, say, engineering students and applied mathematicians are easily accommodated for by this book, a guide in how to select chapters without violating the authors' intentions would have been welcome.

Let me finalise and draw a conclusion. *Optics and Photonics: An Introduction* by F. Graham Smith and Terry A. King is a well-written and very complete textbook, replacing an earlier publication by one of the authors. It is self-contained, allows for significant independent study and therefore very suitable as a textbook for an undergraduate course in optics. Students will benefit very much from using this book as it not only not evades necessary mathematics, but also deals thoroughly, at this level, with the physical phenomenology that is at the basis of modern optics.

Have the authors achieved their ambitious goal of proposing and proving the properties of light by Reason and Experiments? My answer would be a firm Yes with a minor "but". The concept of photons has not been derived anywhere in this text, apart from it's deduction from experiment. There still is a gap in the field of textbooks for a semi-advanced text connecting photonics to quantum electrodynamics.

Frank Witte
University College Utrecht, Utrecht University



Genesis of the BIG BANG

Ralph A. Alpher and Robert Herman
Oxford University Press, 2001
256 pages

"A suddenly a point moves... the first and only one. Here it is creating the Mother from chaos while he becomes the Father."
(Mihai Eminescu, Romanian poet 1850- 1889)

Caught in their daily problems, few people, even physicist among them, have time have time to meditate upon the genesis of the Universe. Cosmogony has been and remained a mysterious, exotic and esoteric field of theoretical physics. Where do we come from and where one we heading for? What is the Universe we live in? On what base did appear and which is the principle that makes it work?

It is difficult to answer these questions due to the essential problems that they imply. The authors of this book had the chance of meeting a famous physicist in their first years of scientific activity. The strong personality of Gamow inspired them to carefully choose the model improved by the reality level approached. They participated in its long-term development. The Big Bang phenomenon tries and succeeds in accurately describing the macrocosm. It's intrinsic beauty charms own starry nights. As a proof for the validity of the model, Alpher and Herman were the first to suggest the existence of the residual "background radiation".

As it was conceived, the book does not represent an attempt to vulgarise science. As a matter of fact, it is a book written by experts for the public at large: physics teachers, students, academics, cosmologist, and philosophers. People of every cultural level may read it. What seems to be the most important, in the fact that, a dense book of theoretical physics, presenting the genesis and evolution of an abstract model in relation with the special relativity, quantum and string theories, can be so easily read. The anecdotal cover introduces the reader in the world where the history, the present and the future of the theory are told with proper words. When the facts cannot be put into words, the reader is advised to analyse the mathematical formulas in the annexes.

The first chapter is an overview of the Big Bang model. The credibility of the assumptions that makes the basis of the model is widely discussed only with scientific arguments. The expansion of the Universe, the cosmic microwave background radiation, the relative abundance of nuclear species, all experimentally observed, suggest a uniform, homogenous, nonstatic Universe being in permanent evolution.

The reader is taught the Big Bang model step by step. The view of a forming Universe is clear in the model only after a few seconds from the expansion. In the second chapter one finds out about the levels of these elucidation so that in the third chapter, one can follow the stages of the development. The Original Einstein Static Model and the Mathematical Nonstatic Models are presented. Special attention is given to the authors' and Gamow's contribution to the genesis and the development of the model. The scientific community considered the article published by Alpher and Gamow on April 1st 1948 a first step in distinctly defining a model of the Universe. Followed by other steps, Further Development of Nucleosynthesis Calculations due not only to Herman and Alpher, but also to physicist and theoreticians Woosley, Wagoner, Fowler, Reeves and so on, the model had complete his evolution.

The Steady State Model, Matter – Antimatter Universe, Theories Based on Time – Dependent Constant Gravitation, the Models Based on Antropic Principle, as alternatives proposed for the Big Bang model are the interesting subject of the Chapter 4. Authors give arguments against and the reader may become in this way a sustainer of the Big Bang.

A special chapter, the fifth one, is reserved to the Cosmic Microwave Background Radiation Observation considered as the relic radiation from an early, hot dense phase of expanding universe. The first theoretical working of the existence of this radiation in its experimental discovery, the first systematic measurements, the further confirmations and the COBE project are considered a permanent and coherent support of the model. Trying to answer the question: "Were does the Big Bang come from?" the authors made pertinent considerations to defend the model, that might look inconsequent otherwise. The solution of the problems raised by the shaping transformations that took place in the first seconds of the Universe's life would certainly be the harmonising of a few mysteries in the Big Bang genesis.

Careful about the scientific argumentation in favour of the model, the authors present in the seventh, eighth and nine chapters, further discussions about the recent tendencies in modern cosmology and the future of the Universe. This considerations seem to be a happy preamble of the annexes in which the basic theoretical elements are given to the anxious reader who wants to know about the mathematical formalism of some of the problems discussed. Not only is it an invitation to logical – mathematical reflection, but also a way of encouraging the thoroughgoing study of the field.

Making a large list of Recommended Reading made by treaties, books and scientific papers, the authors direct those fascinated by the beauty of the field to other new horizons of knowledge and understanding.

On the whole, it is a book that may change concepts, direct efforts, reveal research fields, but give especially a structure to the conscience of the belonging an extremely beautiful Universe, beautiful due to its stubbornness in hiding its secrets.

Hopeful that those able to reveal the mysteries are among the readers of the book, I warmly recommend you its lecture.

Ovidiu Florin Caltun
"Al. I. Cuza" University, Iasi, Romania

Letters

Risks to the Earth from impacts of asteroids and comets

On 26 March 1996, the European Council devoted its resolution 1080 at Saarbrüken to the danger of Earth being hit by a near-Earth object (NEO). Under the same title, Atkinson (2001) discusses this potential danger for humankind in Europhysics News 32/4, cf. fig. 1. Certainly, once our technology has acquired the capability of protecting us against hazardous infalls, we should not miss our chance. But how likely is such an event?

Atkinson bases his estimates on a table of which the literature contains various versions, none with error bars, or with references. The entries fluctuate around some power law. I suspect that their common origin is Shoemaker (1983), who drew a plausible curve through the 1908 Tunguska catastrophe, assuming it to happen every 0.3 kyr. The fluxes of all bodies in the solar system are distributed according to the rough power law $m^2N_m = 10^{-19\pm2}$ g/cm^{2}s, for masses m between 10^{-18}g and 10^{18}g, i.e. from small dust particles all the way up to asteroids ; hence a similar power law is expected to hold for extraterrestrial impacts on Earth. However, the Tunguska catastrophe appears to be a terrestrial event probably the formation of a kimberlite (Ol'khovatov, 1999; Kundt, 2001), thus lowering all impact estimates.

Quite likely, the $\lesssim$10 major historical extinctions of species were caused by meteorite infalls – the last of them 65 Myr ago, forming the Chicxulub crater and eliminating the dinosaurs – and many smaller impacts have been likewise secured, in agreement with a power law. But geophysicists claim there is only one extraterrestrial crater in 30 terrestrial ones, i.e. that volcanic events are some 30 times more frequent than infalls. Figure 2 represents my own assessment of the two sets of events, based on Ol'khovatov's interpretation. For instance the chance of an impact of a km NEO may not be one in 10^5yr but only one in 10^6yr.

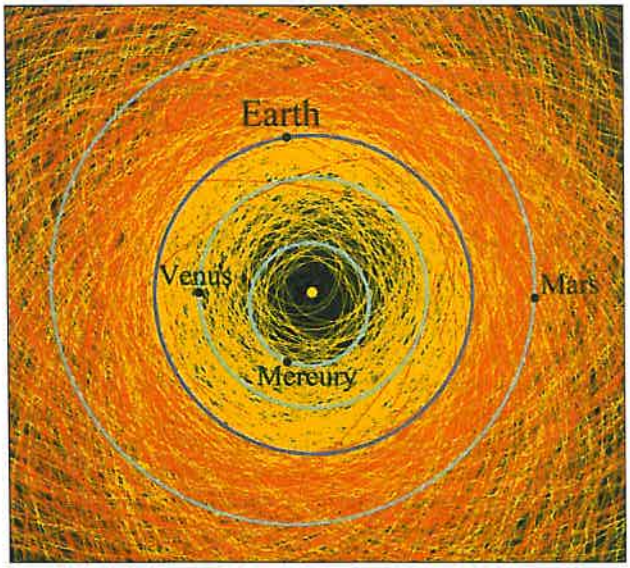


Fig. 1: Orbits of the ≈800 near-Earth objects known in early 2000, centred on the Sun. only asteroids with yellow orbits can collide with Earth, not the red ones. Reproduced from Atkinson (2001).

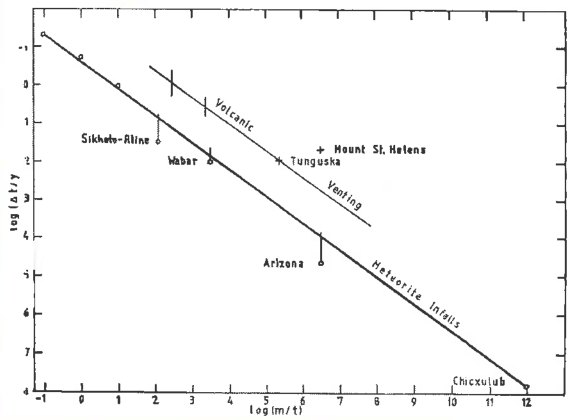


Fig. 2: Repetition rates for (i) meteoritic impacts and (ii) tectonic blowouts, as functions of their liberated energy $E = m\,v^2/2$, or rather their equivalent mass m. For an easier comparison of the two classes of events, the estimated tectonic masses (ii) have been reduced by a factor of 10^2, in order to account for outblow velocities v being some 10 times lower than infall velocities. Reproduced from Kundt (2001).

In the same vein, the impact of comet Shoemaker-Levy 9 on Jupiter in 1994 may not concern us all that much when we remember that impact cross sections scale as M^2 with the mass M of an accretor, i.e. that impacts Jupiter are 10^5 times more frequent than on Earth, for the same embedding fluxes. NEOs form a threat, though perhaps a smaller one than commonly believed.

Wolfgang Kundt, Institute for Astrophysics of Bonn University

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Ol'Khovatov, A. Yu., 1999:
Internet www.geocities.com/CapeCanaveral/Cockpit/3240

Shoemaker, E., 1983: Ann. Rev. Earth Planetary Sciences **11**, 461-494

Reply from the author

Professor Kundt says in his letter that I base my risk "estimates on a table of which the literature contains various versions, none with error bars, or with references". I gave no references because that was not appropriate in an article of this type. But I did give at the end a list for further reading including the web reference (www.nearearthobjects.co.uk) of the UK Task Force's complete Report, which gives full reference to the scientific papers we drew on, and of the many experts we consulted. The reading list also included references to important papers on the subject by Chapman and Morrison (1994), *Impacts on the Earth by asteroids and comets: assessing the hazard*, Nature, **367**, 33; by Rabinowitz D, Helin E, Lawrence K, Pravdo S (2000) *Reduced estimate of the number of kilometre-sized near-Earth asteroids*, Nature, **403**, 165; and to work by Alan W Harris at JPL.

So that the readers of the Europhysics News may be better informed about the latest work on the frequency of impacts, the Editor has kindly allowed me to invite three of the scientists consulted by the Task Force to write a short note on Professor Kundt's letter; this is given below.

Harry Atkinson
Oxfordshire, England

Reply to Kundt on the neo impact hazard

In his letter to EPN, Wolfgang Kundt has raised several issues concerning the frequency of impacts on the Earth by comets and asteroids, and the consequent policy issue of whether public funds should be expended to protect our planet from potential impactors. Specifically, he questions the conclusions of the UK government task force on this subject, described by Harry Atkinson in EPN for May/June 2001. Kundt's main arguments focus on the impact frequency and how it is derived, the nature of the Tunguska event in 1908, and the relative importance of terrestrial and volcanic explosions.

The average frequency of impacts on Earth can be derived in several ways: from the 4-Gyr record of impacts recorded by craters on the lunar maria, from the more recent Phanerozoic impact rate that has produced continental craters on the Earth, and from the current census of near Earth objects (NEOs), primarily asteroids, together with models of their dynamical evolution. All three of these techniques provide a size-distribution for the impactors from the largest crater-forming events down to diameters of the order 100 m. At still smaller sizes, we can also measure the current impact rate of meteoritic debris on the Earth's atmosphere.

The size-frequency distribution of impactors that Kundt questions goes back to the work of Shoemaker (1983) and Shoemaker, Wolfe, and Shoemaker (1990), who based their estimates of average impact frequency primarily on lunar craters, although they used the other methods as well. This size-frequency distribution approximately follows a power law over about 12 orders of magnitude in the mass of the impactors. Each of these techniques gives an absolute flux in terms of impacts of a given energy per unit area on Earth per unit time. Contrary to Kundt's assertion, no assumption is made about the frequency of either Tunguska-size impacts or mass extinction events such as the KT impact. The 1994 impact of comet SL-9 with Jupiter is also irrelevant to the frequency calculations.

It is essentially the composite Shoemaker curve that is reflected in both the US NASA Spaceguard Survey Report (Morrison 1992) and the UK NEO Task Force Report (Atkinson 2000) as well as several published discussions of the impact hazard (e.g., Chapman & Morrison 1994, Toon *et al.* 1997).

Our current (2002) best estimate of the impact frequency has shifted slightly from these values as a consequence of ongoing telescopic surveys of NEOs. We have now achieved more than 50% completeness for the discovery of near-Earth asteroids 1 km or larger, with significant sampling down to a few tens of meters (Harris 1998). The general effect of these new data has been to lower the estimated impact frequency by a factor of two or so relative to that of Shoemaker. Thus, for example, the Shoemaker curve predicted a 10-megaton-energy impact (approximately the size of the Tunguska event) on the whole area of the Earth every few centuries, while the current estimate synthesized by Morrison *et al.* (2002) predicts an average interval of about a millennium. For the 1-km-diameter asteroids, the nominal average impact frequency shifts from once per 200,000 years (the value quoted by Atkinson) to once per 500,000 years. The estimated impact frequencies are still uncertain by at least a factor of 2, and the new values are within the error bars of the previous estimates. In addition, we note that for such rare events the average frequency is of little practical significance. From a policy perspective, we need to know specifically *whether we will be hit*, and where and when it will happen. That is the thrust of both the NASA and UK Task Force recommendations concerning the impact hazard.

Kundt's opinion that the 1908 Tunguska explosion was probably a terrestrial (volcanic) event is irrelevant to the impact frequency conclusions, which have never been based on any assumptions about Tunguska. However, we note the overwhelming bulk of evidence that Tunguska represents a collision with a rocky (asteroidal) body of about 50-60 m diameter and low internal strength, which disintegrated in the lower atmosphere culminating in an explosion of 5-15 MT energy a few kilometers above the surface. Many eyewitnesses observed the incoming meteor, the energy of the explosion was deduced from microbarograph and seismic measurements and from the pattern of fallen trees at the site, and a variety of models (e.g., Chyba *et al.* 1993; Hills and Goda 1993) have reproduced the expected break-up of the projectile in the atmosphere.

Kundt also raises the issue of possible confusion on the part of geologists between volcanic and impact craters. This might have been a valid concern 50 years ago when Shoemaker and other geologists were just beginning to identify the geological and geochemical signatures of impact craters, but today few geologists would fail to make the appropriate distinction between endogenic (volcanic) and exogenic (impact) features. Further, as noted above, the calculated average impact rates are based primarily on lunar, not terrestrial, craters. Unless Kundt wants to argue that the bulk of lunar craters are volcanic, his concerns about terrestrial craters are not relevant to this discussion.

The general impact histories of the Earth and Moon over the past several Gyr are well known, and the primary current population of impactors, the near-Earth asteroids, are being discovered at an unprecedented rate. These objects continue to strike the Earth, and they are capable of causing environmental disasters that far exceed in severity any other known natural hazard. However, the frequency of damaging impacts is low. It is probable that no one will be killed during our lifetimes by a large impact, but it is also possible that hundreds of millions could die next year from the impact of an undiscovered asteroid. The policy issue concerns how society should respond to a risk of such low probability but severe consequences, consequences that could include the end of civilization. We would not want the readers of EPN to be lulled into a false sense of security by the lower risks estimated by Kundt. Nor would we suggest that anyone base their actions simply on a statistical argument - the point is to look and see if we are actually on a collision course with any NEO.

David Morrison, NASA Ames Research Center, Mountain View CA USA
Alan W. Harris, Caltech Jet Propulsion Laboratory, Pasadena CA USA
Clark R. Chapman, Southwest Research Institute, Boulder CO USA

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Acknowledgement

Europhysics News would like to take this opportunity to publish the biographical details of Herman Bondi, which were ommited from the special issue 32/6.

Sir Hermann Bondi born Vienna 01-11-1919. In Britain since 1937, academic mathematical astronomer Trinity College Cambridge 1945–54, King's College, London 1954–67, Churchill College, Cambridge 1983–, public service 1967–84. General Relativity (gravitational waves), cosmology, stellar structure, etc.

Errata

On page 5 of EPN vol. 33 no. 1 there was a typographical error. In paragraph 2, line 13

$$^{239}\mathrm{U}\ (T_{1/2} = 4\cdot 10^9 \text{ years})$$

should have read

$$^{238}\mathrm{U}\ (T_{1/2} = 4\cdot 10^9 \text{ years})$$

Letters, opinions, comments... please send them to: Europhysics News, 34 rue Marc Seguin, BP-2136, 68060 Mulhuose Cedex, France email: epn@evhr.net

activities

CALL FOR PROPOSALS

LIGHT-ION FACILITY EUROPE (LIFE) IN GRONINGEN, JÜLICH AND UPPSALA

The three laboratories **Kernfysisch Versneller Instituut** (KVI) at Groningen, **Institut für Kernphysik** at Forschungszentrum Jülich and **The Svedberg Laboratory** (TSL) at Uppsala jointly offer the means for research in the fields in nuclear and medium-energy hadron physics with proton and heavy-ion beams in a wide energy range at their accelerators AGOR, COSY and the Gustaf Werner-cyclotron/CELSIUS, respectively. They have united their effort in this research field in the framework of LIFE (Light-Ion Facility Europe). Scientists from member states of the European Union and from associated countries are entitled to apply for support to use the beams and facilities of these institutes through contracts signed with the European Commission in the framework of the Access to Research Infrastructures action of the Improving Human Potential (IHP) programme. Proposals will be reviewed by the International Programme Advisory Committees of the respective laboratories and by a joint LIFE Facility Co-ordination Group. Approved projects dealing with research meant for publication in the open literature will be given access to beam lines, experimental equipment, infrastructre, etc. free of charge. The scientists concerned will also be eligible for financial support through the IHP programme to cover their travel and subsistence expenses.

Information about the individual laboratories, available equipment,, proposal forms and deadlines, and other procedures is available from **COSY** : D. Grzonka, tel.: +49 2461 61 4402, fax: +49 2461 3930, e-mail: d.grzonka@fz-juelich.de or http://www.fz-juelich.de/ikp/
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German-Polish EURO-Conference
on
Plasma Diagnostics for Fusion and Applications
Greifswald, Germany September 4-6, 2002

Stimulated by the growing interest in plasma physics and technology, as well as in scientific collaboration between Germany and Poland, the **Max-Planck-Institut fuer Plasmaphysik, EURATOM Ass.,** is sponsoring the **2002 German-Polish EURO-Conference on Plasma Diagnostics**, to be held in **Greifswald, Germany, on September 4-6, 2002**. The Conference is designated for interested scientists, engineers, and students from all countries, and particularly for those from Central and Eastern Europe.

The conference is being organized to be one of the primary sources of community input to the assessment of different **diagnostic methods referring to plasma physics and technology**. The emphasis of the conference will be on **applicability** of the known measuring techniques in various facilities used for **fusion- and technology-oriented experiments**. Discussion of **plasma diagnostics issues and the adaptation of the mastered diagnostic methods to different experimental conditions** will be strongly encouraged.

Scientific Programme and Call for Papers

Plenary and poster sessions will be organized to cover all the topics. Invited speakers for the conference are to be nominated by the International Scientific Committee. Contributed papers will be selected for the oral or poster presentation on the basis of a one-page abstract. The official language is **English**.

Abstracts should be sent by July 12, 2002 by e-mail to the organizers (hartfuss@ipp.mpg.de).

Topics

Diagnostics of Plasma Core
Diagnostics of Plasma Edge and Divertor Diagnostics
Long Pulse Problems and Chances
Fluctuation Diagnostics
Diagnostics of Plasma in PF and Z-Pinch Experiments
Diagnostics of Laser-Produced Plasmas
Diagnostics of Plasmas in Space
Diagnostics of Low Temperature Plasmas
Diagnostics of Plasmas within Technological Devices

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Jerzy Wolowski, IPP&LM, Warsaw, Poland

Registration

Deadline for registration: August 16, 2002

Registration forms with detailed explanations are available on the web site **http://www.ipp.mpg.de/gppd**.

Applications for funding dedicated mainly for young researchers from Eastern Europe should be made directly to the Local Organizing Committee (eggeling@ipp.mpg.de)

Contact: **German-Polish EURO-Conference, Max-Planck-Institut fuer Plasmaphysik, Wendelsteinstraße 1, D-17491 Greifswald**
phone: +49 3834 88 2005 fax: +49 3834 88 2009 e-mail: eggeling@ipp.mpg.de web site: http://www.ipp.mpg.de/gppd