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Editor
David Lee **email:** d.lee@uha.fr

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

Designer
Paul Stearn **email:** p.stearn@uha.fr

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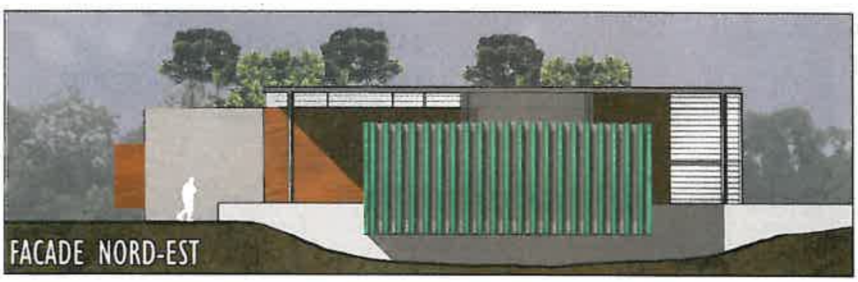
NEWS AND VIEWS

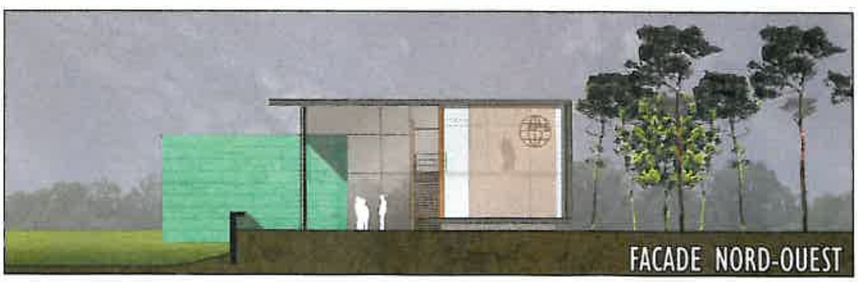
A new home for EPS Headquarters

Chris Rossel, EPS Secretary

In 1997 the EPS Headquarters were moved from Geneva to Mulhouse. This decision taken mainly for financial reasons was the result of several fruitful discussions with the president of the Université de Haute Alsace (UHA), Prof. G. Prado, and the representatives of the city of Mulhouse. These discussions led to a formal framework agreement in May 1996 between the UHA and the EPS represented by its then president, Prof. H. Schopper. Its purpose was to *establish the base for a creative collaboration between both institutions and to study the project of a future building for the Institute of Physics on the campus of the UHA for housing its laboratories and the new offices of the EPS*. As a temporary solution the EPS was offered office space in a building of the Technopôle de la Mer Rouge in Mulhouse, unfortunately not close enough to the University Campus to really promote the expected synergies with the Physics Department. But great hope is round the corner and the plans for a new home for the EPS headquarters are about to become reality!

In Autumn 1999, the UHA and EPS launched negotiations and presented a project within the Plan Etat-Région 2001-2007 to obtain the financing of a common building for 21 million FF. This proposal was not accepted in its entirety. Only the project for a smaller building for the EPS was finally retained with a budget envelope of 5 million FF or 762,000 €. The project will be funded by the French State (80%), the région d'Alsace (10%) and the Département du Haut-Rhin, the city of Mulhouse and the UHA (10%). After several meetings with the president of the University, Mr. G. Binder, and official representatives of the state, region and city, the green light for the planning of the building was finally given in Spring 2001. Based on the requirements for office space formulated by the EPS, the Technical Services of the UHA (maître d'ouvrage and building's owner) launched the first call for projects in November 2001. Out of the 20 architects who responded, an ad-hoc jury made a first selection of three candidates on 18 Dec. 2001. After working out their respective projects the architects were invited to present their work on 25 March 2002. The jury selected ALTER EGO of Mulhouse with an interesting building concept. It is a great pleasure to present here the first views of our future EPS headquarters which will be built next to the Faculté des Sciences et Techniques building, rue des Frères Lumière, home of the Laboratoire de Physique et Spectroscopie Electronique (LPSE). The two storey building with an effective surface of about 380 m2 constructed of materials such as concrete, wood, glass and copper will have a main entrance hall with access to offices on one side and a modular conference hall on the other. The construction work is planned to begin in March 2003 with a possible move of our Secretariat staff in Autumn 2003.





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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X-ray crystallography at subatomic resolution

Alberto Podjarny, Eduardo Howard, Andre Mitschler and Bernard Chevrier
UPR de Biologie Structurale, IGBMC, 1 rue Laurent Fries, 67404 Illkirch, France
Claude Lecomte, Benoit Guillot, Virginie Pichon-Pesme and Christian Jelsch
LCM³B, UMR 7036 CNRS, Faculté des Sciences, Université Nancy I, 54506, Vandoeuvre-lès-Nancy, France

The diffraction of X-rays by molecular crystals is the technique of reference for obtaining three-dimensional information about atomic positions and interactions, information essential for the comprehension of the function and the molecular mechanisms. In the case of small molecules, very precise high resolution measurements allowed the observation of hydrogen atoms of and bond electronic densities. Thus, relations could be established between the deviations from standard stereochemistry of spherical atomic models and the chemical reactivity. In the case of biological macromolecules, one could correlate the spatial arrangement of the components of proteins and nucleic acids to their biological function.

These two types of studies progressed independently during the two last decades, primarily because of the limited resolution of the macromolecular crystallographic results, 2 to 3 Å in the majority of the cases, against 0.5 Å or better for the small molecules. The resolution, which is the minimal separation of the crystal plans giving place to an observable X-ray diffraction spot, is indeed an essential parameter of a crystallographic study. It is directly related to the minimum distance separating the details of the electronic density. A resolution of 2 Å is sufficient to distinguish peptides from a protein or the bases of a nucleic acid, but not the individual atoms, and even less the bond densities.

In the last ten years, various technical improvements, ranging from better techniques of expression and crystallisation to the use of synchrotron sources for measurements of diffraction and algorithms of multipolar and quantum modelling, made it possible to improve considerably the resolution and the quality of the macromolecular models [1]. Biological structural studies with resolutions between 1.5 and 0.9 Å became more current. In this range of resolution, the individual atoms can be clearly distinguished and the hydrogen atoms start to appear. As the errors of atomic position are reduced of an order of magnitude (typically from 0.2 to 0.03 Å), the variations observed from standard stereochemistry start to be significant.

Since 1997, several structures were solved with a resolution better than 0.9 Å, in particular crambin [2], subtilisin [3] and aldose reductase [4]. With such a resolution, the level of the details observed in the best ordered areas approaches that of the small molecules studies. The hydrogen atoms and the bond densities are clearly visible, and the atomic errors of co-ordinates are reduced another order of magnitude (~0.003 Å), which makes the stereochemical differences highly significant. Estimation of the atomic charges starts to be possible.

In what follows, we will discuss two of these cases, crambin and aldose reductase, from the crystallisation and the determination of the structure to the relations between structural details and the reactivity.

▶ **Fig. 1:** Effect of seeding in the crystal growth: a) Dilution 1/10, too many points of nucleation, too many crystals b)Dilution 1/100, few points of nucleation, a crystal of very high quality

Experimental methodology in high resolution studies of macromolecules

Crystal Growth

The growth of the crystals of a biological macromolecule is one of the principal stumbling blocks in the process of determination of the structure, because there is no obvious relation between the nature of the macromolecule and the optimum conditions for crystallisation. The method of crystallisation most frequently used is dialysis in vapour phase, during which a drop containing protein and a stabilising solution (mother liquor) is dyalised against a container containing a precipitating agent. The role of this agent is to establish a competition for water inside the drop, so that the concentration of protein in the drop will increase gradually until the limit of solubility. The protein then precipitates, and, in the successful outcomes, there is nucleation and appearance of crystals.

The characteristic of the macromolecular crystals is that each protein (or nucleic acid) is mainly surrounded by water, and that the contacts with the other macromolecules include only a fraction of total surface.

Very high resolution diffraction comes from highly ordered macromolecular crystals. This implies a very ordered macromolecule


Fig. 1a

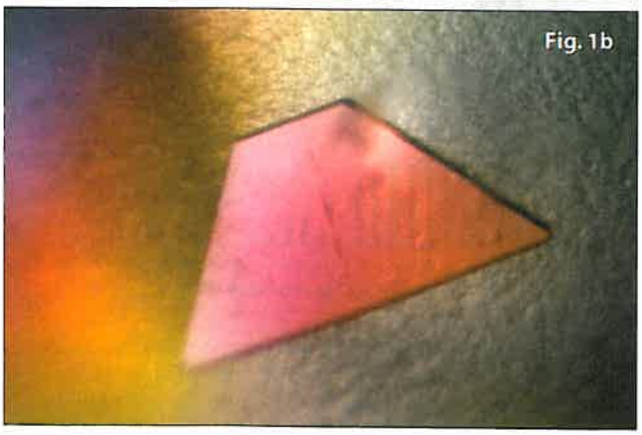


Fig. 1b

features

itself and a large crystal packing interface, and therefore a relatively small proportion of solvent. A very soluble, compact and monomeric molecule will tend to be ordered and to form large interfaces. In general the proteins present a great nümber of polymorphic varieties. Nevertheless, obtaining a crystal form adapted to high resolution remains largely a question of trial and error.

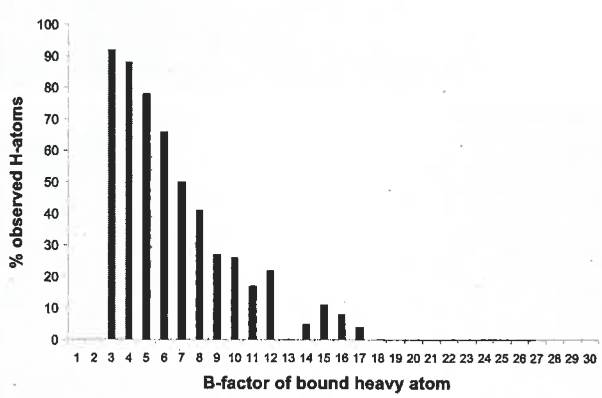
Once one form diffracting to high resolution is found, it is possible to improve it. In the case of aldose reductase [4], several parameters were adjusted to optimise the quality of the crystals, namely:

- crystallisation device: suspended drop or sitting drips;
- the volume of the drop (from 12 to 40 µl);
- the creation of points of nucleation by seeding with micro-crystals;
- the temperature (4 or 24°C);
- the pH (from 5.0 to 6.5);
- the co-crystallisation with ligands.

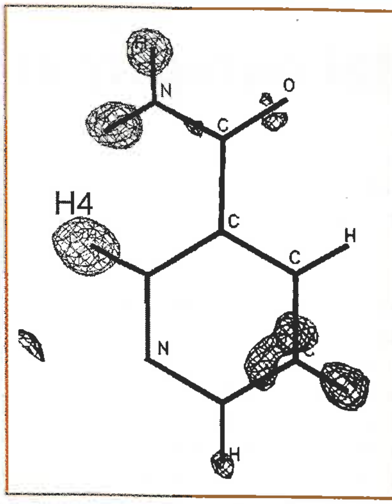
An example of the effect of seeding is given in figure 1.

X-rays are obtained by acceleration (or deceleration) of electrons. The first sources were vacuum tubes, in which X-rays are emitted when a flow of electrons strikes an anode. The rotating anodes, which allow a better dissipation of the heat released during this process, were a first improvement, which allowed a brightness increase of two orders of magnitude. But the most decisive progress came from the synchrotron sources, where the acceleration of an electronic beam at relativistic speed produces highly collimated X-rays. The first synchrotrons offered a gain of brightness of 6 orders of magnitude, and the sources of third generation such as the ESRF (Grenoble) or the APS (Argonne) represent a gain of 14 orders of magnitude.

The brightness of the source is the principal factor in the measurement of the signal of diffraction to high resolution, because the average intensity of diffracted X-rays strongly decreases with the resolution. But it is not the only factor. Other developments were necessary, such as (i) the cryogenic techniques, to avoid or slow down the degradation of the crystal exposed to the beam of X-rays, (ii) the optics of the installation, which ensures a highly parallel and uniform beam, (iii) the technology of the detector, for the fast measurement of a large amount of diffraction data and (iv) the algorithms of reduction of the data. In the case of aldose reductase, the diffraction data were recorded from cooled crystals



▲ Fig. 2: Percentage of the hydrogen atoms observed according to the temperature factor of the bonded heavy atom in the structure of aldose reductase, refined has 0.66 Å resolution [5].



◄ Fig. 3: Electronic density of difference map Fobs-Fcalc, calculated without hydrogen atoms (contour 2σ) in the region of the nicotinamide cycle in the structure of Aldose Reductase [5].

at 100° K, on a synchrotron of third generation, the Advanced Photon Source in Argonne, Illinois, with an optimised beam optics and a large CCD detector (22.1 × 22.1 cm²), fast and with low background noise.

Computing Methodology for ultra high resolution crystallography

Independent atom model refinement (IAM)

Single crystal X-ray diffraction data lead to structure factor amplitudes. The structure factors are the Fourier transform of the electron density $\rho_{dyn}(\mathbf{r})$ of the unit cell of volume V and parameters $\mathbf{a}_i$, i = 1, 3.

$$F(\mathbf{H}) = \int_{\text{unit cell}} \rho_{dyn}(\mathbf{r}) \exp(2\pi i \mathbf{H}.\mathbf{r})$$

$$|\mathbf{H}| = 2\sin\theta/\lambda,\ \theta \text{ is the Bragg angle, } \lambda \text{ is the wavelength}$$

$$\rho_{dyn}(\mathbf{r}) = \int_{\text{unit cell}} \rho_{static}(\mathbf{r}-\mathbf{u})\, P(\mathbf{u})\, d^3u$$

$P(\mathbf{u})$ is an atomic probability distribution function which Fourier transform is the Debye Waller factor. The crystal is triply periodic, therefore the Fourier transform has non zero values only on reciprocal lattice points defined by the reciprocal vectors

$$a^*_i = (\mathbf{a}_j \wedge \mathbf{a}_k)\, V^{-1}$$

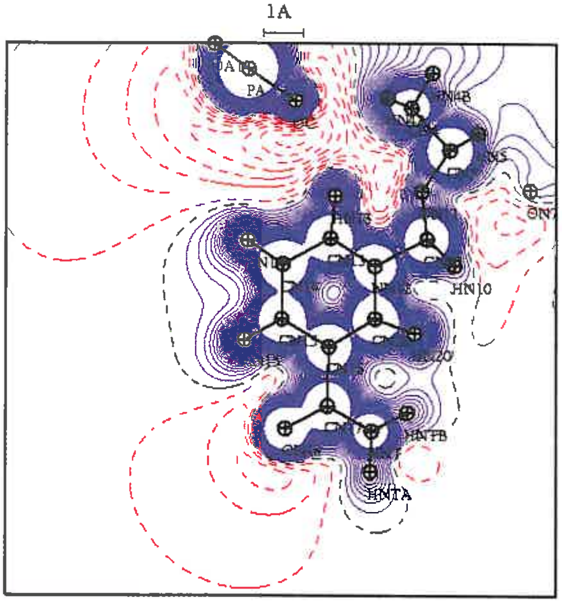
F(H) are complex quantities and we must know both their amplitude and phase for directly calculating $\rho_{dyn}(\mathbf{r})$ by inverse Fourier transform. Methods for ab initio phase determination are still under development but they are not the aim of this paper.

As the electron density is mainly concentrated around atomic positions, the structure factor may be expressed as:

$$F(\mathbf{H}) = \Sigma_j f_j(|\mathbf{H}|) \exp(2\pi i \mathbf{H}.\mathbf{r}_j) \exp(-0.25 B_j |\mathbf{H}|^2)$$

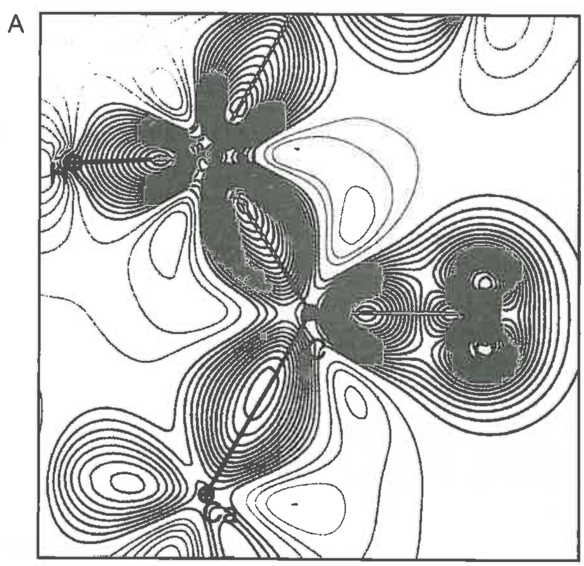
Where r are the atomic positions, B_j the Debye Waller factors and f_j the atomic scattering factors; these latter the are Fourier transform of the electron density of the free neutral atom (Independent Atom Model, I.A.M.).

This equation is the basic one for most macromolecular crystallographic refinements which fit the observed |F|'s values using a model with four parameters per atom, i.e. atomic coordinates and isotropic Debye Waller factor. At the usual resolution for macromolecular crystallography (2Å<d<3Å), the resolution and



▲ **Fig. 4:** Electrostatic potential generated by NADP$^+$ (calculated from subatomic resolution diffraction data). Contours 0.1 e Å^{-1}, continuous line V > 0, dotted line V < 0.

therefore the number of observations |F| is not enough for determining the total number of parameters and it has to be completed with relations imposing a standard stereochemistry for the polypeptidic chain. At higher resolution one can observe deviations to the standard geometry. If the data are at atomic resolution (d<1.2Å), the isotropic temperature factor may be replaced by an anisotropic factor and the resulting accuracy of atomic positions is good enough to validate shifts from the standard geometry.



▲ **Fig. 5:** Model deformation density of the peptide group calculated from the electron density data base [12]. Contours 0.05 e Å^{-3}, continuous ρ > 0, dotted ρ< 0.

Subatomic resolution (d<0.8 Å): hydrogen atoms

At subatomic resolution, d<0.8Å, informations on valence electron density distribution may be obtained when the B Debye Waller factor is lower than 4Å^2. Hydrogen atoms also clearly show up. Deviations from the spherical atom model appear as electron density peaks in the bonds on deformation electron density maps (calculated by the difference between the observed electron density and the IAM density).

In aldose reductase 54% of hydrogen atoms were identified as well as most of the bonding density in the bonds of the active site of the protein. The probability to observe these features is directly related to the B factor [2, 5] (figure 2).

Finding the position for H atoms is extremely important for the catalytic reaction because it determines the protonation state and therefore the activity of the catalytic residues [5]. Figure 3 shows the protonation state of the nicotinamide cycle in the active site of aldose reductase. This cycle is a part of NADPH coenzyme which is transformed to NADP$^+$ during the enzymatic reaction. The hydrogen atom H4 clearly shows up which demonstrates that the coenzyme is in the NADP$^+$ state.

Charge density refinement: the multipolar model

The IAM model is too primitive to take into account all the information existing at subatomic resolution and a new model derived from small molecules crystallography has been developed which is called charge density refinement [6, 7].

In contrast to the IAM model where all atoms of a molecule or protein are supposed to be neutral with a spherical valence electron distribution (promolecule), the valence charge density is modelled by a sum of multipolar pseudo atoms lying at atomic positions. The valence electron density of such a pseudo atom is projected on the basis of real spherical harmonics functions centred on each pseudoatom.

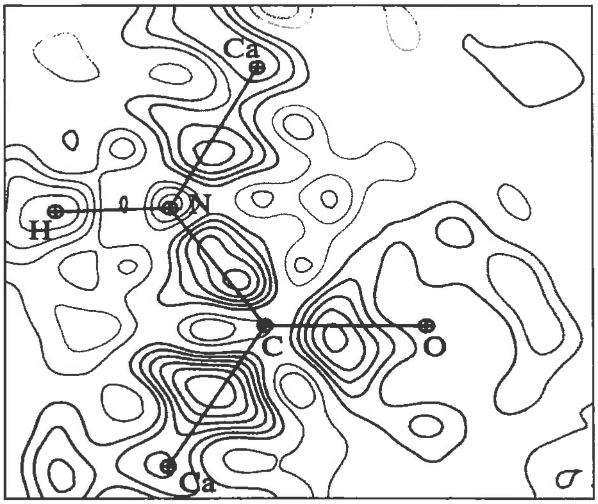
$$\rho_{static}(\mathbf{r}) = \rho_{coeur}(\mathbf{r}) + P_v\kappa^3\rho_v(\kappa \mathbf{r}) + \sum_{l=0}^{lmax} P_{lmp}R_l(\mathbf{r})y_{lmp}(\theta,\varphi) \quad (1)$$

The radial functions used are of Slater type. First applications of this formalism to mono or dipeptides were calibration of ab initio HF calculations: it was clearly shown that triple zeta basis sets with polarisation functions were necessary to quantitatively reproduce the X-ray diffraction experiment [8]. The P_v, P_{lmp}, κ, κ' (dilation contraction of the density) are directly obtained from least squares refinement against the structure factors amplitudes [2, 7].

This analytical representation of the charge density is used to calculate crystal and molecular properties such as electrostatic potential, electric field, net charges, higher moments [9] and topology of the electron density [10]. As an example figure 4 gives the experimental electrostatic potential around NADP$^+$, which is the cofactor of most enzymatic oxydo-reduction reactions. This potential was derived from X-ray multipolar analysis [11].
High resolution X-ray diffraction studies have been performed in Nancy on all amino-acids or monopeptides existing in Nature in order to precise their electron density distribution [12, 13].
These studies allowed building a data base of atomic charge density parameters (P_v, P_{lm}, κ, κ' see formula 1). These parameters were shown to be transferable to peptide functions in proteins [13]. Figure 5 gives the static deformation electron density calculated from the data base parameters for the CONH peptide group.

$$\delta\rho(\mathbf{r}) = \sum_{j=1}^{Nat}\left[\rho_{base}(\mathbf{r}-\mathbf{r}_j) - \rho_{promolecule}(\mathbf{r}-\mathbf{r}_j)\right]$$

This deformation density reveals the valence electron redistribution due to covalent interactions. The electrons built up in the



▲ Fig. 6: Residual electron density averaged over the 34 non disordered peptide groups of crambin after an IAM modelling. Contours as figure 5.

bonding region and the oxygen lone pairs are clearly evidenced. Then, the next step has been testing this data base on a protein. X-ray diffraction data on crambin, which is a small 46 residues protein, have been measured on BW7A line of DORIS (Hamburg) synchrotron to a resolution of d = 0.54 Å, which is still the world record for a protein [14]. This protein possesses all necessary criteria like low Debye Waller factors (B ~3 Å^2) for ordered parts of the protein. Taking advantage of the repetition of the same CONH chemical motif along the polypeptide main chair, the average dynamic deformation map over the 34 non disordered peptide residues was calculated according to:

$$\delta\rho(\mathbf{r}) = \Sigma_{H'} (F_o - F_c) \exp(i\varphi_c) \exp(-2i\pi\, \mathbf{H}.\mathbf{r})$$

F_c/φ_c are respectively the structure factor amplitude and the phase calculated from the IAM model (neutral, spherical atoms). F_o is the structure factor amplitude derived from the synchrotron experiment.

This average deformation density map displays significant residual density in the bonds between non hydrogen atoms and on oxygen lone pairs. These features clearly demonstrate that the IAM model does not provide an adequate fit to the experimental diffraction data.

After transfer of the statistically significant multipole from the data base and after multipolar refinement with MOPRO [7], the residual density does not exceed 0.06 e Å^{-3} which is about the estimated error: the progressive flattening of residual density features through the refinement stages is convincing physical evidence of real improvement in the modelling [2]. At the end of the refinement, the static deformation electron density of the average peptide residue (figure 7) is in almost quantitative agreement with that derived from an triple zeta HF calculation on a single monopeptide [8].

Conclusion

Ultra high resolution structure determination opens a new frontier in macromolecular crystallography; observing protonation states and shifts to standard geometry shows that protein structures are not rigid entities on which functionally active residues are linked, but active machineries in which most residues play an active role for the fine tuning of the mechanism. Subatomic resolution studies also allow determination of charge and electronic distribution and electrostatic potential for the atoms in the active site of enzymes and enable a better understanding of their function. New important applications are foreseen in the determination of electronic properties and oxidation states of reactive metallic centres in redox and electron transfer metalloproteins. With the enhancement of charge density modelling, the development of the data base of transferable parameters [12] and the continuing technological advances in experimental synchrotron crystallography, analysing the electronic structure of macromolecules has considerable unexplored potential.

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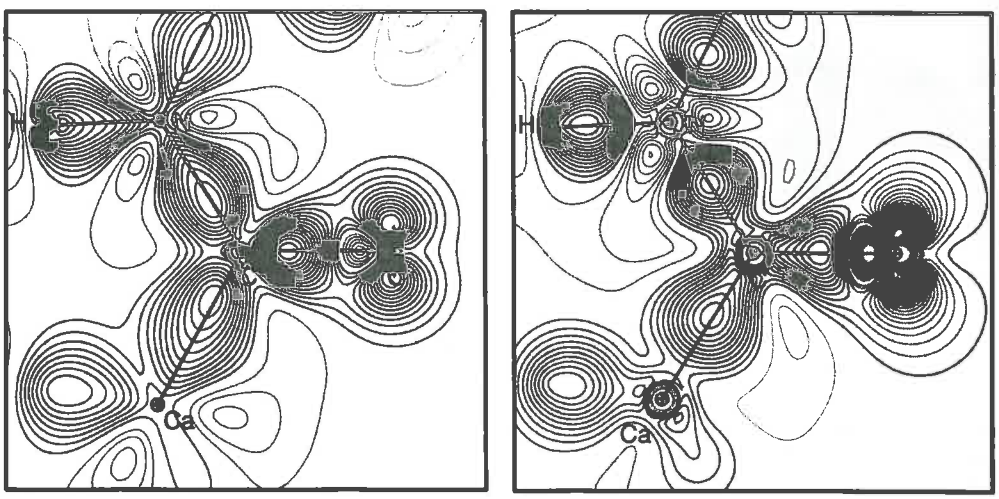

◄ Fig. 7: Static deformation density of a peptide plane in crambine a), compared to a HF SCF calculation on a single peptide b); contours: some as figure 5.

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Fossil structure in the galactic halo:

Trying to reconstruct the formation history of the Milky Way

Amina Helmi, Max Planck Institute for Astrophysics, Garching, Germany

Those that have looked up in the heavens will have noticed a band of silvery light across the sky, which is known as the milky way. This light has its origin in millions of distant stars that are too far to be resolved with the naked eye. This "milky way" is what one observes looking edge on into the disk of our Galaxy. For myself, and perhaps many other astronomers, the fascination for astrophysics lies in the combination of the incredible beauty of the heavens, an example of which is the milky way shown in Figure 1, and the prospect of being able to explain how the Universe works under the simple laws of physics.

There are many billions of galaxies like the Milky Way in the Universe. Understanding how these systems formed is one of the fundamental questions in Astrophysics today. Popular theories of galaxy formation and evolution propose that galaxies are the result of mergers and accretion of smaller sub units, that come together through the action of gravity. This 'hierarchical' (bottom-up) build up of structure in the Universe has gained substantial observational support in the last twenty years, mostly from observations of very distant galaxies caught in the process of forming, as shown by the Hubble Space telescope (see Figure 2).

Any successful theory of galaxy formation should also be able to reproduce the properties of the Milky Way. Our Galaxy constitutes a benchmark in galaxy formation studies, since we have access to multidimensional information (like the positions and velocities of individual stars) which is not available for other systems. This wealth of data has the power of strongly constraining any scenario of galaxy evolution.

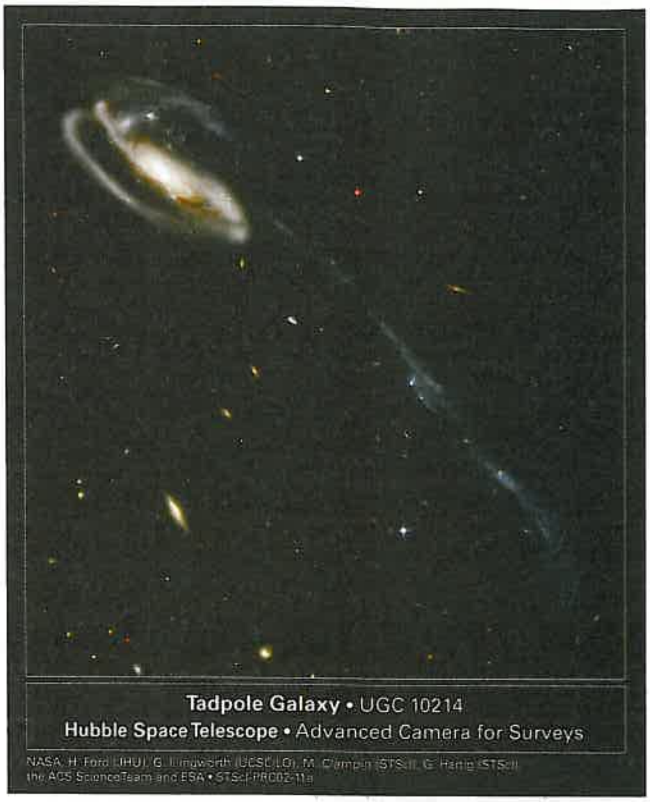
In the context of the hierarchical scenario, understanding how the Milky Way was assembled is equivalent to reconstructing its 'genealogical family tree'. This contains information on the progenitors of our Galaxy, that is, on the mergers it has experienced, the properties of the merging objects, when these events took place, etc. These in turn must have determined its shape, the ages and chemical composition of the stars that form it, their motions... In this article I will try to address how we might be able to reconstruct the Milky Way merging history. Clearly, the ultimate test of the hierarchical formation of our Galaxy consists in actually finding the signatures of the mergers the Milky Way experienced over its life. Thus we need to understand what those signatures are, and what are the observational requirements to recognise them.

Let us start by studying in some detail how mergers of galaxies proceed. As an example, consider the simpler case of a satellite galaxy orbiting the Milky Way, shown schematically in Figure 3. Like in the problem of the Moon orbiting around the Earth,

▲ **Fig. 1:** Panoramic view of the sky showing the Milky Way. Individual stars are shown as white dots. The "Milky Way" clouds, actually the combined light of dim, unresolved stars in the densely populated galactic plane, are interrupted by dramatic dark dust lanes (Lund Observatory, Sweden).

features

▶ **Fig. 2:** This picture of the galaxy UGC 10214 was taken by the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope. It shows long streamer of stars originated in the compact galaxy visible in the upper left corner of the image. Strong gravitational forces from the interaction created the long tail of debris, consisting of stars and gas that stretch out more than 280,000 light-years (STSci).



gravity is the main driving force. The critical difference lies in the fact that we are dealing with N-body systems, where N is very large. Although gravity is a relatively simple force, the fact that it is long-range,and that one has to deal with large numbers of particles (representing stars for example), implies that one often has to recur to numerical simulations to properly model the evolution of galactic systems.

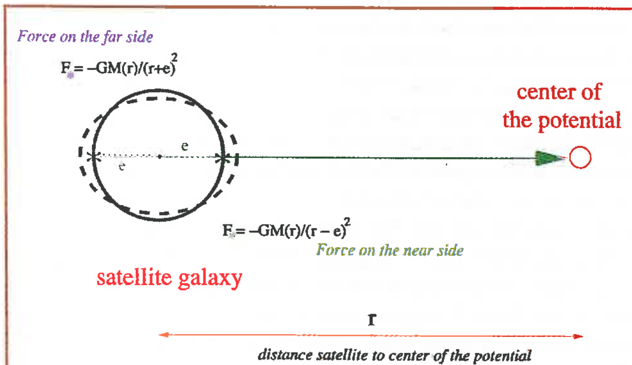
In the case we are interested in (a small galaxy orbiting a larger one), the stars in the satellite system feel a differential gravitational pull caused by the Milky Way galaxy. Due to the finite size of the satellite the force it feels on the side closer to the Galactic centre is different from that on the opposite side, which produces a deformation of its shape. This deformation is analogous to the tides the Earth experiences due the Moon's gravitational pull.The stars in the satellite may become unbound if their internal energy is positive. Once they are released, they become, as it were, part of the Milky Way galaxy. They continue moving on similar orbits as the satellite but may now drift away from it, as shown in Figure 4. This drift is caused by the fact that their energies are slightly different from that of the satellite, as are their orbital frequencies.

An ensemble of disrupted satellite galaxies, leaving behind the characteristic trails of stars shown in Figures 2 and 4, will give rise to a spheroidal component. Stellar halos, which are a diffuse spheroidal component of galaxies, are thus a natural reservoir of the debris of past mergers.

Conservation laws are very powerful tools in physics, and they are particularly useful in the context of trying to recover the history of a Galaxy. One such law is the conservation of energy. Let us consider our problem of a small ensemble of stars (a satellite galaxy) orbiting around an (otherwise static) galaxy. Initially the stars in the ensemble are all strongly concentrated in space and share essentially the same motion. This implies that they all have very similar energies. If the energy is a conserved quantity (an assumption which may not always hold), then at the present time all the stars in the ensemble will also have the same energy. Thus they would still be clumped in energy space. Clearly, if one would be able to measure directly the energies of the stars in our Galaxy one should discover the distribution is not smooth but formed by many lumps, which simply reflect the systems that gave rise to our Milky Way. However, it is not always possible to determine the energy of the stars in the Galactic halo, since it implies knowledge of the Galactic potential,as well as the 3D location and motion of the star. Thus the question shifts to understanding how do such "energy" lumps look like in observable coordinates, like those directly accessible through observations. How does the distribution of stars evolve in time? What is their spatial distribution at the present time, what is their velocity distribution, are there any hints of substructure?

Another useful conservation law is stated by Liouville's theorem,which describes the conservation of volume (or density) inphase-space: $dV = d^3x\, d^3v =$ constant. As we mentioned above,once a star is released from its parent system, it starts to drift away (see Figure 4). Thus d^3x increases in time. Since the volume is conserved in phase-space, this implies that locally d^3v has to decrease in time. Thus stars originating in the same system, should have very similar motions even after a very long time has passed since they were released from their parent system. They would be predicted to be clustered in structures that we call *streams*.

What is the observational evidence in favour of the scenario described above? First of all, out of the thirteen or so known satellite galaxies of the Milky Way, three of them are currently showing signs of being strongly perturbed by tidal forces. The Large and Small Magellanic Clouds have lost a good fraction of their gas content,which now forms a stream which closely follows the orbit of the system, similar to what is shown in Figure 2. Another very spectacular example is the Sagittarius dwarf galaxy which is

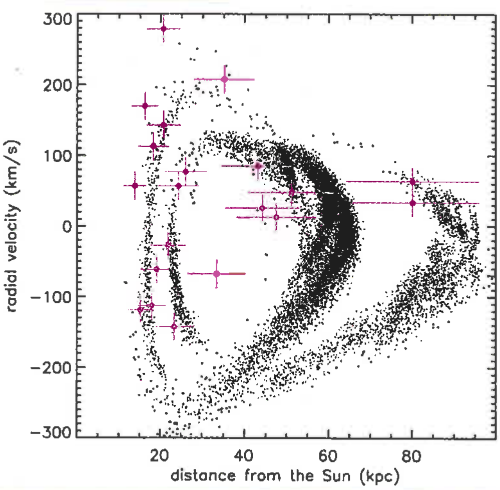


▲ **Fig. 3:** Schematic picture showing the tidal force exerted on a small satellite due to a larger (in this case) central object. The force on a star in the side closer to the centre of the potential is $F_{near} = -GM(r)/(r_{sat} - \epsilon)^2$, while for a star located on the far side it is $F_{far} = -GM(r)/(r_{sat} + \epsilon)^2$, implying a softer pull. This differential force is what produces the deformation in the shape of the satellite galaxy.

▲ **Fig. 4:** Numerical simulation of the disruption of a small galaxy, probably similar to the Sagittarius dwarf, a current satellite of the Milky Way. The panel on the left shows the initially strongly concentrated satellite. As time goes by, the satellite is progressively destroyed by the gravitational pull of the large galaxy, giving rise to trails of stars which closely follow the orbit of their progenitor. The panel of the right shows that eventually the streams overlap spatially, and the stars become part of a roughly spherical halo around the central galaxy. The image in the centre of each panel corresponds to the neighbouring disk galaxy Andromeda, which closely resembles the Milky Way (Picture from Bill Schoening, Vanessa Harvey/REU program/NOAO/AURA/NSF).

being completely torn apart just now, and which will not be visible as a coherent unit the next time it comes close to the centre of the Galaxy, in about 10^9 years.

But was this also a common phenomenon in the past? What fraction of the stars that are now part of the Galaxy came aboard such a satellite like those we see today? How do we gain access to that information? For the outer halo, where the dynamical timescales are long, trails of stars, such as those shown in Figure 4, should remain coherent until the present day. Therefore the positions of stars should suffice to determine how lumpy the outer stellar halo is. There are several efforts going on to try to discover these structures. The Spaghetti Project Survey (the analogy clearly is that the halo is a bowl of spaghetti!) is one of such projects that aims to identify fossil relics of destroyed galaxies. The collaboration is carrying out a large-scale study optimised to identify distant halo stars on the basis of their peculiar (characteristic) colours (which are due to their low metal-abundance). These stars are then observed with a spectrograph to determine their velocity along the line of sight. This additional piece of information has enabled them to discover streams associated to material lost by the Sagittarius dwarf galaxy indifferent passages near the Galactic centre, as shown in Figure 5.



▲ **Fig. 5:** A slice of phase-space r vs v_r for a model of the disruption of the Sagittarius dwarf galaxy. The particles from this model of Sagittarius are shown here as black dots. The solid circles with error bars correspond to halo stars observed by the Spaghetti collaboration. The agreement between the observed location and motion of most of these stars suggests that they were in the past part of the Sagittarius dwarf galaxy.

A second very large survey which has started to map the distribution of stars in the Galaxy is the Sloan Digital Sky Survey. It has in the past two years revealed tantalising substructures in the galactic halo, most of which can also be linked to the disruption of Sagittarius.

Most of the action, however, is expected to have taken place closer to the centre of the Galaxy, and at very early times. Recovering fossil structures in the inner stellar halo, or in the vicinity of the Sun, is considerably more difficult. The key issue is that the timescales are very short in this region of the Galaxy, and soon streams overlap in space, as shown in the last panel of Fig. 4 and in Fig. 5. This makes very difficult distinguishing observationally one stream from the other on the basis of positional information alone, and even the knowledge of the velocity along the line of sight, which is relatively easy to measure, does not improve the situation. The degeneracy can only be broken with 6 dimensional information, so that also the motions projected in the sky are known. However, measuring proper motions requires either a very long time span (of the order of fifty to a hundred years) or very accurate positional information (better than 1 microarcsecond), which can only be achieved from space.

Currently there are not very many large samples of halo stars with sufficiently accurate motions to enable us to break up the velocity distribution into the hundreds of streams expected. The HIPPARCOS satellite provided proper motions of about 100 halo stars, which combined with ground-based observations, allowed astronomers to discover the first direct indication of a past merger in the Solar neighbourhood: a small galaxy probably similar to current satellites of the Milky Way. To do recover more such events, and be able to determine the relevance of this process in the build up of our Galaxy, astrometric satellite missions are necessary. The European Agency satellite GAIA is one such mission, that will measure with very high accuracy the motions of millions of stars in our Galaxy and in our nearest neighbours. Such large samples of stars with six-dimensional phase-space information will undoubtedly shed light on the fundamental questions concerning the origin and evolution of galaxies. Missions such as GAIA will allow us to reconstruct the genealogical family tree of the galaxy that we call our home: the Milky Way.

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Laser-induced nuclear physics and applications

K.W.D. Ledingham[1,2], R.P. Singhal[1], P. McKenna[1], I. Spencer[1]
[1]Department of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, Scotland
[2]AWE plc. Aldermaston, Reading, Berkshire, RG7 4PR, UK

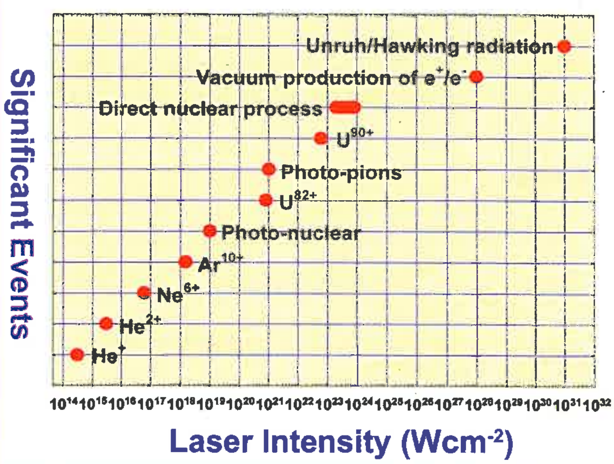
This story started nearly fourteen years ago when two of us KWDL and RPS were discussing with Joe Magill (Karlsruhe) the seminal theoretical paper by Boyer, Luc and Rhodes (1988) on the possibility of using a high intensity focused laser beam (10^{21} Wcm^{-2} and 248 nm) to induce fission in ^{238}U.

Many probes had been used to induce fission, particularly neutrons both fast and slow. Other nuclear probes had also been used e.g. protons, deuterons, α particles and heavy ions as well as non nuclear beams e.g. γ-rays, electrons and muons. It is perhaps not surprising for a sufficiently intense light source to induce fission especially since a number of lasers had pulse powers of a terawatt (10^{12} W) or even a petawatt (10^{15}W). A terawatt is the total electrical power generated in the USA.

This initiated, for the research team at Glasgow working in collaboration with Imperial College and the plasma physics group at the Rutherford Appleton Laboratory and now many other groups around the world, an exciting new area of physics that we have named "laser-induced nuclear physics".

Historical Perspective

The mechanism of the interaction of charged particles with intense electromagnetic fields has been considered for more than fifty years. This was one of the first explanations put forward by the early workers to explain the origin and energies of cosmic rays, e.g. Fermi (1949). Simply the idea is as follows: a charged particle in an intense electromagnetic field is accelerated initially along the direction of the electric field. The v×B force causes the particle's path to bend into the direction of travel of the wave. In large fields the particle's velocity rapidly approaches the velocity of light and it tends to travel with the EM wave gaining energy from it. In astrophysical situations the solar corona was thought to be one of the sources of the electromagnetic waves. Such astrophysical phenomena are the counterparts of the machines built on the earth to accelerate particles to high energies.



▲ Fig. 1: Some significant atomic and nuclear events as a function of laser intensity. At present the highest laser intensities reach 10^{21} Wcm^{-2}. Plans are already in place to build lasers 100 times more intense.

In the late seventies, Tajima and Dawson (1979) realised that by focusing laser light into a plasma medium, very high accelerated energies could be generated. They proposed the construction of a laser-electron accelerator which could be created when an intense laser pulse produced a wake of plasma oscillations (volumes of low and high densities of electrons). Similar to a boat creating a bow wave or wake as it moves through water, a bunch of high velocity electrons creates a wake of plasma waves as it passes through a plasma. They demonstrated with computer simulations that existing glass lasers of 10^{18} Wcm^{-2} could yield electron acceleration gradients of 100 GeV/m. It is known that conventional accelerators are limited by electrical breakdown at fields of about 20 MV/m; at these fields the electrons are torn from the atoms in the accelerator's support structure. Thus these plasma particle accelerators promise fields more than 1000 times stronger that those of the most powerful conventional accelerators.

> Similar to a boat creating a bow wave... a bunch of high velocity electrons creates a wake of plasma waves...

It is instructive to show what experiments can be carried out with very intense laser sources. Figure 1 presents threshold intensities of some of the significant events that can occur. There is no significance to the y co-ordinate apart from spatially separating the events to ease viewing. With a 1 ps pulse laser at 1 µm wavelength, He gas is ionised at about 3×10^{14} Wcm^{-2}. As the intensity increases, the inert gases become multiply ionised and between 10^{18-19} Wcm^{-2} photon induced nuclear reactions are energetically possibly. Close to 10^{21} Wcm^{-2}, pion production can take place- the first of the elementary particles. At the very high intensities of 10^{28} Wcm^{-2}, it can be shown that electron-positron pairs can be created from the vacuum.

Using lasers to accelerate particles

Since the beginning of laser science in the early 1960s there have been continuous efforts made to increase the power of lasers. Today laser systems are readily available with several Terawatts (1 TW=10^{12} Watts) of power and some of the largest laser systems such as the VULCAN laser (Figure 2), situated at the Rutherford Appleton Laboratory, near Oxford in the UK, will shortly be able to reach Petawatts (10^{15} Watts of power). This laser is currently able to deliver over 100 Joules of energy in a picosecond (10^{-12} s) pulse.

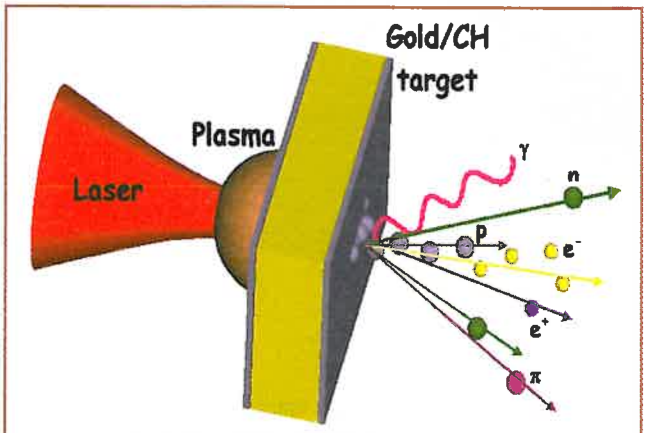
The VULCAN laser uses Nd:glass (optical glass doped with Neodymium) as its amplifying medium. This is an excellent

◄ **Fig. 2:** The VULCAN laser facility at the RAL near Oxford, UK.
a) Part of the VULCAN laser Nd:glass amplifier chain.
b) The interaction chamber used for nuclear experiments.
c) Installation of the optics for the new Petawatt upgrade.

medium for producing pulses of high energy and short duration, although at these enormous power densities, damage to the amplifying medium can occur. This problem is overcome by the use of an ingenious technique called Chirped Pulse Amplification (CPA) (Perry & Mourou 1994). In CPA, a short, low power laser pulse is first stretched temporally, then amplified at a safe level to reduce the power density in the amplifying medium, before it is finally re-compressed to its original duration. CPA has brought about a revolution in peak laser powers, and all ultra-high power laser systems today employ this technique.

Since the beginning of laser science... there have been continuous efforts made to increase the power of lasers.

After being stretched, amplified and recompressed, the VULCAN pulses are transported under vacuum to a large interaction chamber, where the experiments take place. Typically one pulse is delivered every 20 minutes. The pulse is focused to an area of a few μm^2 using a parabolic mirror. In this small area an intensity of 10^{20} Watts per square centimetre is achieved. Unique and extreme states of matter are produced in the resulting interaction. Electric fields of the order of 10^{11} Vcm^{-1} are generated along with huge alternating magnetic fields close to 10^9 Gauss, only a factor of 1000 smaller than the magnetic field of a typical black hole. Under these conditions a target is completely ionised creating a plasma of positively and negatively charged particles.



▲ **Fig. 3:** The interaction of a high intensity, short laser pulse with a solid target leads to the production of high energy particles and radiation.

The short powerful laser pulse sets up electrostatic waves within the plasma by displacing the negatively charged electrons with respect to the heavier positively charged ions. This displacement of the charges creates electrostatic acceleration fields. Within the strong laser electric fields the electrons oscillate at close to the speed of light introducing relativistic effects. They can be accelerated over large to very high energies by the induced fields. Electron energies of over 200 MeV have been created in this way.

In a target of sufficiently high atomic number Z (number of protons in the nucleus), the accelerated electrons are slowed down in the target material emitting high energy photons (γ-radiation) via 'bremsstrahlung' or 'braking radiation'. The energy of these gamma-rays can reach up to the maximum energy of the accelerated electrons. It is these high energy photons which can be used to induce nuclear reactions in materials.

Another effect produced in the interaction of the high intensity, short laser pulse with a target is the production and acceleration of ions. This occurs when the high energy electrons exit the target setting up strong electrostatic fields. The ions from the plasma are dragged by the energetic electrons as a result of charge separation and are accelerated to energies of tens of MeV. In particular protons are accelerated with great efficiency. These high energy protons and heavier ions are also capable of inducing nuclear reactions.

In its simplest form the interaction of an intense short pulse of laser radiation with a target can be viewed (Figure 3) as an exchange of energy from the laser pulse through a number of successive energy transfers leading to the production of high energy particles and radiation which have applications to nuclear physics.

Photo-Nuclear Physics With a Light Source

Nuclear fission: Laser-induced fission of ^{238}U was observed at the VULCAN laser facility at RAL in 1999. Uranium nucleus has a rugby ball shape—the attractive short-range nuclear force balances the repulsive coulomb force due to the 92 protons to give the nucleus its prolate deformation. Because uranium is such a large nucleus, it behaves like a drop of liquid. Supply of energy from the outside (from, e.g., an incident neutron or γ-ray) causes the nucleus to vibrate and rotate. The vibrations produce increased average distance between the nucleons resulting in a reduction of the binding effects of the short-range nuclear force, while the infinite ranged coulomb force is little affected. At some stage in the vibrations, the attractive forces are no longer able to hold the nucleus together and it flies apart with two main fragments, a few evaporated neutrons and gamma rays. The fragments are more tightly bound than the original uranium nucleus and the excess energy is released as kinetic energy of motion. Fission of uranium produces a double-headed asymmetric yield distribution of fragments with maximum yields at mass numbers about 95 and 140 corresponding to the neutron magic numbers of 50 and 82 (Figure 4).

Evidence for fission events is normally carried out by detecting the characteristic gamma rays from the principal fission fragments.

Three 80 J pulses from the VULCAN laser irradiated a 1.75 mm Ta target backed with a 2 mm thick ^{238}U sample. The ^{238}U was shrink wrapped in plastic to contain any gaseous activity and enclosed in an aluminium container. The laser pulses produced a flux of high energy gamma rays which induced fission in uranium nuclei as described above. Unambiguous characteristic gamma rays from the fission fragments ^{134}I, ^{138}Cs and ^{92}Sr were observed. From the measured intensities, it is concluded that about a million fission events are generated by a 10^{19} Wcm^{-2} laser shot in a 2 mm thick ^{238}U target. The predictions of Boyer, Luk and Rhodes (1988) were confirmed and the experimental field of laser-induced nuclear physics was born.

> The predictions... were confirmed and the experimental field of laser-induced nuclear physics was born.

(γ,n) reactions: The relativistic electrons produced by the laser-matter interaction have an exponential energy distribution characterised by the parameter kT, called the electron or plasma temperature. kT is an important parameter in plasma physics but is difficult to measure accurately by current technology. Laser-induced (γ,n) reactions provide a reliable method of measuring kT.

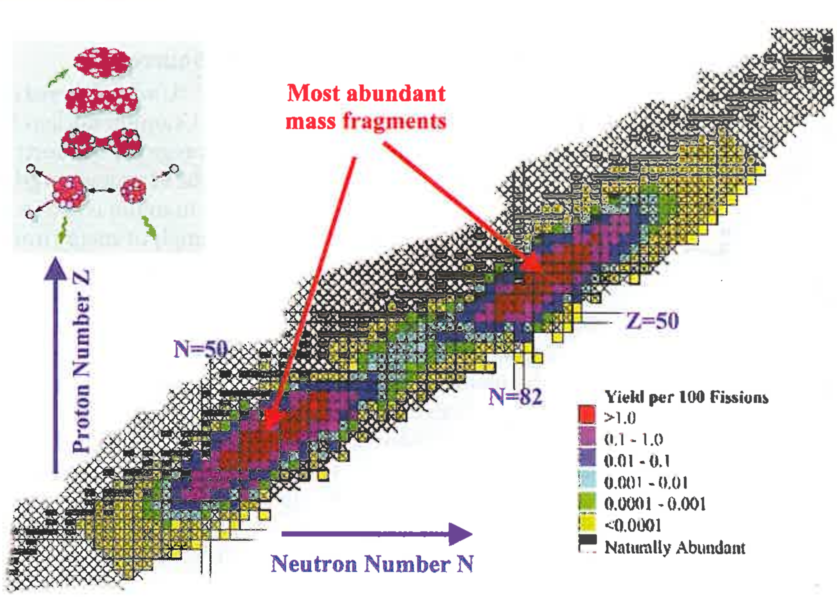
While fission addresses overwhelmingly the collective aspects of nuclear response to excitation, (γ,n) reactions deal with the way individual nuclei decay by the emission of neutrons when excited by gamma rays of energy greater than a threshold value—the Q-value. For most nuclei the Q-value is 8 MeV or larger. Below the Q-value, nuclei remove the excess excitation energy by emitting one or more photons.

In the excitation process, a high energy photon is absorbed by a nucleus. The excited nucleus may be visualised as one in which the protons are oscillating against the neutrons—the nuclear giant dipole resonance (GDR). The probability of absorbing a photon of energy near the peak of this broad resonance is very high. When excited, GDRs mostly decay by emitting a proton or a neutron—neutron emission being the more probable. After the emission of a neutron, the resulting nucleus has an excess of protons and exhibits positron-decay activity—it is a β^+ emitter. The positron annihilates with an electron in the material to produce two γ rays travelling in opposite directions. Positron activities may be measured accurately by counting the two 511 keV annihilation γ rays in a coincidence arrangement. A measurement of the activity as a function of time provides the decay curve that may be used to characterise and identify the half life of the daughter nucleus.

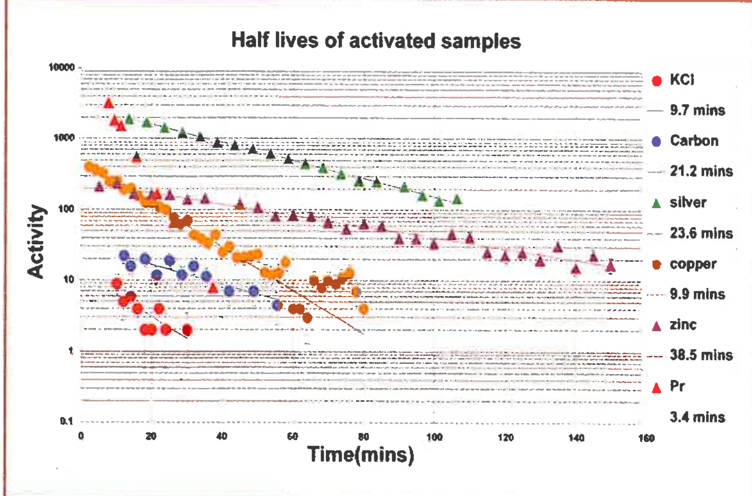
(γ,n) reactions were studied for a range of nuclei by irradiating a 1.8 mm thick Ta target with an 80J VULCAN laser pulse. In Ta, the high energy electrons produced bremsstrahlung γ rays whose energy spectrum is completely determined by that of the electrons. The γ rays induced positron activity in a range of targets (Figure 5). The half-lives determined are in excellent agreement with the accepted values. The absolute value of the activity for a target nucleus is primarily determined by the γ ray energy distribution and the known cross sections for the excitation of the GDR. A comparison of induced activities in nuclei with different Q-values provides a measurement of the γ ray energy spectrum and hence that of the electrons in the plasma. A plasma temperature kT = 1.6 MeV was determined by comparing the (γ,n) data for ^{12}C (Q = 18.7 MeV) and ^{63}Cu (Q = 10.9 MeV). This unique plasma diagnostic method has been further developed by using (γ,n) and (γ,3n) data from a ^{181}Ta target, obviating the need to measure the relative target thicknesses etc and measurements can be made from just one sample.

Laser Production of Protons and Applications

When an ultra-intense laser is focused on to a solid target, beams of protons are produced both in front of and behind the target. The protons originate from hydrocarbon and water impurity layers on the target surfaces. For laser intensities $>10^{19}$ Wcm^{-2}, these protons have energies in the MeV regime. Hence, ultra-intense lasers can generate protons of energy similar to that of a



◄ **Fig. 4:** Uranium fission mass yields according to proton and neutron number. The most abundant fragments correspond to the neutron "magic numbers" of 50 and 82.



◄ **Fig. 5:** Decay plots of the products of (γ,n) reactions. The half-lives measured agree well with the accepted values.

cyclotron or van de Graaf, although the equipment used and acceleration physics are vastly different.

Conventional accelerators are used in nuclear medicine to generate beams of MeV protons to induce nuclear reactions in materials, e.g. the reaction ^{18}O(p,n)^{18}F. The product isotope is a short-lived positron emitter. These sources are used in the medical imaging technique Positron Emission Tomography (PET). The patient receives by injection a pharmaceutical labelled with a short-lived positron emitting isotope. The radio-pharmaceutical is metabolised at specific sites in the body. Positrons annihilate with background electrons to produce two back-to-back gamma rays. By detecting these gamma rays using a ring of gamma cameras, specific sites of high pharmaceutical uptake in the body can be imaged. PET has proven to be extremely useful in imaging e.g. blood flow, amino acid transport and brain tumours. Figure 6 shows the equipment involved in PET.

The main positron emitting nuclei used in PET are ^{11}C, ^{13}N, ^{15}O and ^{18}F. The proton-induced nuclear reactions commonly employed to produce these isotopes are shown in Figure 6. The reason that protons are the preferred projectile rather than e.g. gamma rays is that the radio-isotope produced has a different atomic number from the original isotope, and the positron emitter can be separated from the carrier using fast chemistry.

Ultra-intense lasers offer an alternative source of MeV protons and hence PET sources. While the large-scale VULCAN laser was used in the proof-of-principle experimentation described below, it is envisaged that practical applications of laser-produced protons will be found through the use of "table-top", high-repetition rate lasers operating at similar intensities. A laser proton source will be more compact, less expensive and require less shielding and maintenance than conventional accelerator technology.

Proton and PET isotope production was studied using the VULCAN laser operating at 10^{20} Wcm^{-2} and incident on a thin aluminium target. Protons originate from hydrogen impurities on the target surfaces, since a proton is an ionised hydrogen atom.

The numbers and energies of protons produced both in the direction of the incoming laser (in front of the target) and behind the target were measured (Figure 7). Behind the target, protons of energies up to 37 MeV were produced whereas in front of the target, the maximum energy was 25 MeV. Both proton beams obtained may be used to produce PET isotopes.

To demonstrate laser PET isotope production, a boron sample was placed in front of the Al target and the laser was focused onto target. The boron sample was then removed from the target chamber and placed in a coincidence system which counts positron annihilation events. The activity of the sample was measured as a function of time as shown in Figure 7. A half-life of 20.3±0.4 minutes was measured. This showed that the PET isotope ^{11}C was produced (accepted half-life 20.34 min), via the reaction ^{11}B(p,n)^{11}C. At the time of laser irradiation, around 200 kBq of ^{11}C was produced.

Although ^{11}C is a useful isotope for PET, the favoured isotope at the moment is ^{18}F. The reaction usually employed to produce ^{18}F is ^{18}O(p,n)^{18}F. The integrated cross section for this reaction is about half that of the reaction ^{11}B(p,n)^{11}C, hence it is feasible that a laser pulse of 10^{20} Wcm^{-2} could produce 10^5 Bq of ^{18}F.

A typical patient dose for PET is 2×10^8 Bq although 8×10^8 Bq sources are necessary to allow time for fast chemistry to be performed for isotope separation. Assuming that a VULCAN type laser could deliver 10 Hz, then the integrated activity after 500 s is about 10^9 Bq. At the time of writing, an immense amount of work is being conducted on high repetition rate table-top lasers worldwide, to test the feasibility of proton production on such systems.

Amazing Physics at Laser Intensities > 10^{22}Wcm^{-2}

Exciting new phenomena are expected at these intensities. We shall mention a few dealing specifically with nuclear and particle physics.

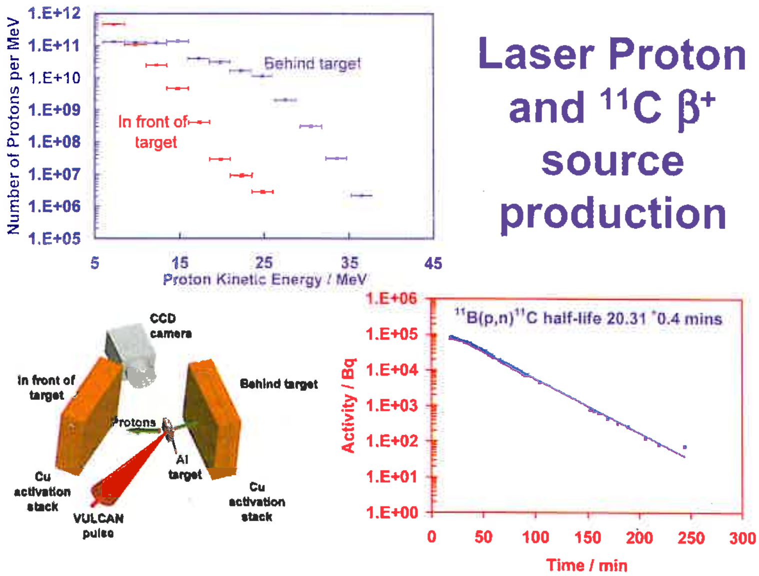
Direct interaction with the nucleus

As the laser intensity is increased above 10^{22} Wcm^{-2}, the oscillating electric field can affect the protons in the nucleus in exactly the same way as the electrons in the plasma. At 10^{24} Wcm^{-2} this energy

Positron Emission Tomography

^{14}N + p ⇒ ^{11}C + ^{4}He	^{11}C	20 min
^{13}C + p ⇒ ^{13}N + n	^{13}N	10 min
^{15}N + p ⇒ ^{15}O + n	^{15}O	2 min
^{18}O + p ⇒ ^{18}F + n	^{18}F	110 min

▲ **Fig. 6:** A PET medical imaging scanner and the nuclear reactions commonly employed to produce PET isotopes.



◀ **Fig. 7:** (Bottom left) experimental set-up defining "in front of" and "behind" target directions, (top left) proton energy spectra measured in front of and behind target, (bottom right) decay plot of the PET isotope ^{11}C produced via laser generated proton beams.

is 2.5 keV and at 10^{28} Wcm^{-2} shifts of the order of 250 keV occur. Thus lasers could radically alter nuclear energy levels and decay half-lives making it possible to shorten the lifetimes of nuclear waste.

Fusion by direct laser acceleration of ions

Ions oscillating in the field of a laser beam can gain sufficient energy from the field to cause fusion to take place in a D, T target. At 10^{21} Wcm^{-2} the collision energy is on average about 8 keV with a corresponding fusion cross section of ~ 10^{-4} barn. At 10^{22} Wcm^{-2} the collision energy is about 80 keV. The peak of the DT fusion cross section (5 barns) occurs at about 100 keV. Most fusion reactions take place in very large scale facilities but now it will be possible to study fusion reactions in this novel way for the first time for a range of low Z nuclei with small laser systems.

Particle Physics

At 10^{22} Wcm^{-2} the radiation pressure on electrons in a thin target can reach values greater than 10^{12} bar and for very thin targets, resulting in low plasma densities, electron energies in excess of 100 GeV are possible. Electron energies as high as 10^{14} eV may be generated at laser intensities of 10^{26} Wcm^{-2} and 10^{16} eV at 10^{28} Wcm^{-2}.

The production of azimuthal magnetic fields in excess of 10^9 G close to the fields which exist at the surfaces of black holes is another exciting possibility. At 10^{28} Wcm^{-2} electron positron pairs can be produced from the vacuum and at 10^{30}Wcm^{-2} Hawking/Unruh radiation using counter propogating laser beams can be generated. A γ-γ collider using counter propogation laser-induced photon beams has also been the subject of recent study.

Epilogue

Since we embarked on this exciting journey of laser-induced nuclear physics and its applications some four years ago, we have never ceased to be amazed at the world-wide interest it has generated. However as with many scientific endeavours, the most important results that come from the study of a new technology may be totally unexpected...

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About the authors

Ken Ledingam is a Professor of Physics at the University of Glasgow and a William Penney Professor of Laser Nuclear Physics (AWE plc). His research career has spanned nuclear physics, in particular photo-nuclear physics and β-decay, laser-matter interactions, e.g. Resonant Ionisation Mass Spectrometry, multiphoton processes, femtosecond laser mass spectrometry and applications and now his career has come full circle in the study of laser-induced nuclear physics.

Ravi Singhal is a senior lecturer at the University of Glasgow. His research career also began in nuclear physics, before investigating laser interactions with atoms and molecules, and now most recently laser-induced nuclear physics.

Paul McKenna is a research associate at the University of Glasgow. His main research interests include the dynamics of atoms and molecules in intense laser fields, and laser-induced nuclear physics.

Iain Spencer completed his PhD. Thesis, entitled "Laser-induced Nuclear Physics" in 2001 and is currently an R.A. at the University of Glasgow.

SECRETARIATS

Mulhouse
34 rue Marc Seguin, BP 2136
F-68060 Mulhouse Cedex, France
TEL/FAX +33 3 89 32 94 40 / 32 94 49

Secretary General David Lee
EMAIL d.lee@uha.fr

Conferences Patricia Helfenstein
EMAIL p.elfenstein@uha.fr

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EMAIL p.stearn@uha.fr

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EMAIL p.padovani@uha.fr

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Nador u. 7
H-1051 Budapest, Hungary
TEL/FAX +36 1 317 35 10 / 317 68 17
EMAIL mlazar@office.mta.hu

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17 avenue du Hoggar
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EMAIL zjb@le.ac.uk

J.M. Fernandez de Labastida
Depto. Fisica de Particulas
Universidad de Santiago de Compostela
ES-15706 Santiago de Compostela Spain
TEL/FAX +34 981 56 31 00 (Ext. 13993)/+34 981 52 10 91
EMAIL labasti@fpaxp1.usc.es

R. Menzel
Universität Potsdam
Institut für Physik
Postfach 60 15 53
DE-14415 Potsdam Germany
TEL/FAX +49 331 977 1026/+49 331 977 1134
EMAIL menzel@rz.uni-potsdam.de

C. Sebenne
Laboratoire de Mineralogie Cristallographie
Université Pierre et Marie Curie
Case 115, FR-75252 Paris Cedex 05 France
TEL/FAX +33 1 44 27 45 10 /+33 1 44 27 45 41
EMAIL Claude.Sebenne@lmcp.jussieu.fr

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Deutsche Forschungsanstalt f. Luft- und Raumfahrt e.V.
Postfach 90 60 58
D-51147 Cologne (Köln-Porz), Germany
TEL/FAX +49 2203 60 10 / 69 57 68
EMAIL berndt.feuerbacher@dlr.de

R. Monot
EPFL
DP - IPE Ecublens
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 693 33 31 / 693 36 04
EMAIL rene.monot@epfl.ch

R. Scherm
Fachbereich Q.1 "Physikalische Grundlagen"
Physikalische-Technische Bundesanstalt
Postfach 3345
D-38023 Braunschweig, Germany
TEL/FAX +49 531 592 81 00 / 592 8106
EMAIL reinhard.scherm@ptb.de

J. Vaagen
Fysik Institutt
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Allegaten 55
N-5007 Bergen, Norway
TEL/FAX +47 55 58 27 24/ 55 58 94 40
EMAIL jans.vaagen@fi.uib.no

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EMAIL ducloy@lpl.univ-paris13.fr

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TEL/FAX +41 31 631 3254/+41 31 631 4896
EMAIL mceh@bluewin.ch

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Saeumerstr. 4
CH-8803 Rueschlikon Switzerland
TEL/FAX +41 1 724 85 22 / +41 1 724 89 56
EMAIL rsl@zurich.ibm.com

Treasurer P. Reineker
Abteilung Theoretische Physik
Universitaet Ulm
Albert-Einstein-Allee 11
DE-89069 Ulm Germany
TEL/FAX +49 731 502 29 13 / +49 731 502 29 24
EMAIL peter.reineker@physik.uni-ulm.de

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Universita di Pisa
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Via F. Buonarroti, 2
IT-56127 Pisa Italy
TEL/FAX + 39 050 844 517 / +39 050 844 333
EMAIL maria.allegrini@df.unipi.it

Executive Committee Members
D.J. Brown
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UK-Dorridge Solihull B93 8NS United Kingdom
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President of RSEF
Instituto de Fisica Fundamentale
Serrano, 123 - CSIC
ES-28006 Madrid Spain
TEL/FAX +34 9 1 585 51 96 / +34 9 1 585 53 98
EMAIL gerardo@cc.csic.es

K. Gaemers
Institute for Theoretical Physics
University of Amsterdam
Valckenierstraat 65
NL-1018 Amsterdam Netherlands
TEL/FAX +31 20 525 5772 / +31 20 59 25 778
EMAIL gaemers@science.uva.nl

D. Krupa
Institute Of Physics
Slovak Academy Of Sciences
Dubravska cesta 9
SK-84228 Bratislava Slovakia
TEL/FAX +421 2 5941 0514 / +421 2 5477 6085
EMAIL krupa@savba.sk

Z.R. Rudzikas
State Institute of Theoretical Physics and Astronomy
Academy of Sciences of Lithuania
A. Gostauto 12
LT-2600 Vilnius Lithuania
TEL/FAX +370 5 262 0668 / +370 5 212 4694
EMAIL tmkc.plls@wllb.lt

C. Zerefos
Laboratory of Atmospheric Physics
Physics Department
Aristotle University Of Thessaloniki
POB 149
GR-54066 Thessaloniki Greece
TEL/FAX +30 31 99 8041 /+30 31 28 3752
EMAIL zerefos@auth.gr

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F-75230 Paris Cedex 05, France
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EMAIL cor@moka.ccr.jussieu.fr

Secretary P. Helfenstein
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TEL/FAX +420 2 20 51 34 11 / 2 31 23 1 84
EMAIL nadrchal@fzu.cz

Secretary D.L. Nagy
Department of Nuclear Physics,
KFKI
Research Inst. for Particle and Nuclear Physics
PO Box 49
H-1525 Budapest 114, Hungary
TEL/FAX +36 1 395 9037 / 1 395 9151
EMAIL nagy@rmki.kfki.hu

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Secretary E. Szilagyi
KFKI
Research Institute for Particle and Nuclear Physics
PO Box 49
H-1525 Budapest 114, Hungary
TEL/FAX +36 1 392 2222 (ext. 3962) / 1 392 2518
EMAIL szilagyi@rmki.kfki.hu

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Secretary D.L. Nagy
KFKI
Department of Nuclear Physics
Research Institute for Particle and Nuclear Physics
PO Box 49
H-1525 Budapest 114 Hungary
TEL/FAX +36 1 395 2517 / +36 1 392 2518
EMAIL nagy@rmki.kfki.hu

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Chair G. Gehring
University of Sheffield
Department of Physics & Astronomy
Hicks Building
UK-S3 7RH Sheffield, United Kingdom
TEL/FAX +44 114 22 24299 / +44 114 272 8079
EMAIL g.gehring@sheffield.ac.uk

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EMAIL elbaz@univ-lyon1.fr

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TEL +44 1782 680 126
EMAIL e.f.slade@btinternet.com

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Astronomical Institute
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TEL/FAX +31 30 25 35 209 / 25 35 201
EMAIL kuijpers@phys.uu.nl

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Department of Physics and Astronomy
University College London
Gower Street
UK-London WC1E 6BT, United Kingdom
TEL/FAX +44 20 7679 7797 / 7679 3460
EMAIL nigel.mason@ucl.ac.uk

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F-91405 Orsay Cedex, France
TEL/FAX +33 169 35 20 52 / 169 35 21 00
EMAIL francoise.masnou@lac.u-psud.fr

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UK-Brighton BN1 9QH, United Kingdom
TEL/FAX +44 1273 60 67 55 / -
EMAIL e.a.hinds@sussex.ac.uk

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Chair P. Lambropoulos
IESL-FORTH
PO Box 1527
D-Heraklion Crète 71110
Greece
TEL/FAX +30 81 39 13 84 or -82 / 81 39 13 05
EMAIL labro@iesl.forth.gr

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Université de Provence
PIIM, UMR 6633 CNRS-UAM1
Centre de St-Jérôme, Case C 21
F-13397 Marseille Cedex 20
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School of Physics and Engineering Physics
Gothenburg University & Chalmers University of Technology
S-41296 Gothenburg, Sweden
TEL/FAX +46 31772 3272 / 772 3496
EMAIL Eleanor.Campbell@fy.chalmers.se

Vice-Chair D. Gerlich
Institut für Physik
TU Chemnitz
DE-09107 Chemnits, Germany
TEL/FAX +49 371 531 31 35 / +49 371 531 31 03
EMAIL gerlich@physik.tu-chemnitz.de

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Institut für Ionenphysik
Universität Innsbruck
Technikerstr. 25
A-6020 Innsbruck, Austria
TEL/FAX +43 512 507 6240 / 507 2932
EMAIL tilmann.maerk@uibk.ac.at

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Département de Physique Theorique et Appliquee
CEA Ile de France
B.P. 12
F-91680 Bruyeres le Chatel, France
TEL/FAX +33 1 69 26 47 11 / 69 26 70 26
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Chair E. Tiemann
Institut fur Quantenoptik
Universitat Hannover
Welfengarten 1,
D-30167 Hannover, Germany
TEL/FAX +49 511 762 3306 / 762 2211
EMAIL tiemann@mbox.iqo.uni-hannover.de

Vice Chair G. Pichler
Institute of Physics
Bijenicka cesta 46
HR-10000 Zagreb, Croatia
TEL/FAX +385 1 469 8888 / 469 8889
EMAIL pichler@ifs.hr

Condensed Matter Division

Chair H.R. Ott
Lab. für Festkörperphysik
ETH Hönggerberg
CH-8093 Zürich, Switzerland
TEL/FAX +41 1 633 23 11 / 633 10 77
EMAIL ott@solid.phys.ethz.ch

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University Road
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EMAIL zjb@le.ac.uk

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Max-Planck - Institut fuer Metallforschung
Heisenbergstr. 1
D-70569 Stuttgart, Germany
TEL/FAX +49 711 689 1920 or 1921 / 689 1922
EMAIL dietrich@mf.mpg.de

Secretary & co-opted member K. Mecke
Max-Planck Institut für Metallforshung
Heisenbergstr. 1
D-70569 Stuttgart, Germany
TEL/FAX +49 711 6891936 / 6891922
EMAIL mecke@mf.mpg.de
EMAIL mecke@fluids.mpi-stuttgart.mpg.de

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Chair H. Adrian
Institut für Physik
Johannes Gutenberg-Universität Mainz
Staudingerweg 7
D-55099 Mainz, Germany
TEL/FAX +49 6131 39 23637 / 39 24076
EMAIL Hermann.Adrian@uni-mainz.de

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Chair G. Strobl
Fakultät für Physik
Albert-Ludwig-Universität
Hermann-Herder-Strasse 3
D-79104 Freiburg, Germany
TEL/FAX +49 761 203 5857 / 203 5855
EMAIL strobl@physik.uni-freiburg.de

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Dep. de Fisica de la Materia Condensada-ICMA
Facultad de Ciencias
Universidad de Zaragoza-CSIC
E-50009 Zaragoza, Spain
TEL/FAX +34 976 761215 / 761229
EMAIL ibarra@posta.unizar.es

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NL-6525 ED Nijmegen, The Netherlands
TEL/FAX +31 24 365 22 22 / 365 21 20
EMAIL fasolino@sci.kun.nl

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Chair A. Simon
Max-Planck-Institut fuer Festkoerperforschung
MPI
Heisenbergstrasse 1
DE-70569 Stuttgart
Germany
TEL/FAX +49 711 6891 640 / 6891 091
EMAIL a.simon@fkf.mpg.de

Secretary G. Hermann
Max Planck Institut fuer Festkoerperforschung
MPI
Heisenbergstrasse 1
D-70569 Stuttgart
Germany
TEL/FAX +49 711 6891 641 / 6891 091
EMAIL g.hermann@fkf.mpg.de

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Institut für Physikalische Chemie
Universität Bonn
Wegelerstrasse 12
D-53115 Bonn, Germany
TEL/FAX +49 228 73 22 53 / 73 25 15
EMAIL K.wandelt@uni-bonn.de

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Leiden Institute of Chemistry, Gorlaeus Laboratories
Leiden University
Einsteinweg 55
P.O. Box 9502
NL-2300 RA Leiden, The Netherlands
TEL/FAX +31 71 527 4250 / 527 4451
EMAIL a.kleyn@chem.leidenuniv.nl

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Chair U.M. Titulaer
Institute for Theoretical Physics
Johannes Kepler University Linz
Altenbergerstrasse 69
AT-4040 Linz, Austria
TEL/FAX +43 732 2468 8551 / +43 732 2468 8585
EMAIL titulaer@tphys.uni-linz.ac.at

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Department of Radiation Sciences
Uppsala University
PO. BOX 535
SE-75121 Uppsala, Sweden
TEL/FAX +46 18 471 0000 / +46 18 471 3513
EMAIL gtibell@tsl.uu.se

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Chair H. Ferdinande
Universiteit Gent
Vakgroep Subatomaire en Stralingsfysica
Proeftuinstraat 86
BE-9000 Gent, Belgium
TEL/FAX +32 9 264 65 39 / +32 9 264 66 97
EMAIL hendrik.ferdinande@rug.ac.be

Secretaries E. Valcke & T. Formesyn
Universiteit Gent
Vakgroep Subatomaire en Stralingsfysica
Proeftuinstraat 86
BE-9000 Gent, Belgium
TEL/FAX +32 9 264 65 33 / +32 9 264 66 97
EMAIL elke.valcke@rug.ac.be
EMAIL tamara.formesyn@rug.ac.be

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Interim Chair I. Isaksen
University of Oslo, Envrionmental Modeling, Norway
TEL/FAX 47 22 85 58 22 / -

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Chair M. Spiro
CEA Saclay
DSM – DAPNIA – SPP
Bât. 141
FR-91191 Gif-sur-Yvette Cedex, France
TEL/FAX +33 1 69 08 23 50 / 69 08 64 28
EMAIL spiro@dapnia.cea.fr

Secretary J. Wess
Universität München
Institut für Theoretische Physik
Theresien Str. 37
DE-80799 München 2, Germany
TEL/FAX +49 89 23 94 43 72 / +49 89 28 05 24 8
EMAIL julius.wess@physik.uni-muenchen.de

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Chair A. Kugler
Nuclear Physics Institute ASCR
CZ-250 68 Rez, near Prague, Czech Republic
TEL/FAX +420 2 6617 3285 / 2 2094 1130 – 2 2094 0220
EMAIL kugler@ujf.cas.cz

Secretary A. Zenoni
Dipartimento di Chimica e Fisica per l'Ingeneria e per i Materiali
University of Brescia
Via Valotti 9
I-25123 Brescia, Italy
TEL/FAX +39 030 3715 700 / +39 030 2091 271
EMAIL zenoni@bs.infn.it

Treasurer S. Aberg
Lund Institute of Technology,
Department of Mathematical Physics
PO BOX 118
SE-221 00, Lund, Sweden
TEL/FAX +46 46 222 9633 / +46 46 222 4416
EMAIL Sven@matfys.lth.se

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Chair P.A. Lindgard
RISOE National Laboratory
Material Research Department
DK-4000 Roskilde, Denmark
TEL/FAX +45 4677 4706 / +45 4677 4790
EMAIL p.a.lindgard@risoe.dk

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Chair F. Wagner
Max-Planck- Institut für Plasmaphysik
Greifswald Branch
Wendelsteinstr. 1
D-17491 Greifswald, Germany
TEL/FAX +49 3834 88 2000 / 88 2009
EMAIL fritz.wagner@ipp.mpg.de

Vice-Chair J.B. Lister
CRPP / EPFL
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 693 34 05 / 693 51 76
EMAIL jo.lister@epfl.ch

Vice-Chair R. Bingham
Rutherford Appleton Laboratory
Chitton Didcot
UK- OX11 0QX, England
TEL/FAX +44 1 235 445 800 / 1 235 445 848
EMAIL r.bingham@rl.ac.uk

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Chair J. Meyer-ter-Vehn
Max-Planck-Institut für Quantenoptik
MPI
Hans-Kopfermann-Str. 1
DE-85748 Garching, Germany
TEL/FAX +49 89 32905 137 / +49 89 32905 200
EMAIL meyer-ter-vehn@mpq.mpg.de

Dusty & Colloidal Plasmas Section

Chair G.M.W. Kroesen
Eindhoven University of Technology
Department of Physics
PO BOX 513
NL-5600 MB Eindhoven, Netherlands
TEL/FAX +31 40 2474 357 - +31 40 2472 550 (Secret.) / +31 40 2456 050
EMAIL g.m.w.kroesen@tue.nl

Quantum Electronics & Optics

Chair G. Huber
Institut für Laser-Physik
Universität Hamburg
Jungiustr. 9-11
D-20355 Hamburg, Germany
TEL/FAX +49 40 428 38 36 28 / 428 38 62 81
EMAIL huber@physnet.uni-hamburg.de

Secretary S. De Silvestri
Politecnico di Milano
Dipartimento di Fisica
Piazza Leonardo da Vinci, 32
IT-20133 Milano, Italy
EMAIL sandro.desilvestri@fisi.polimi.it

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Instituto Mediterraneo de Estudios Avanzados, IMEDEA
CSIC-UIB
Campus Universitat Illes Balears
ES-07071 Palma de Mallorca, Spain
TEL/FAX +34 971 173 229 / 971 173 426
EMAIL maxi@imedea.uib.es

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Chair L. Rivkin
Paul Scherrer Institute, PSI
CH-5232 Villigen
Switzerland
TEL/FAX +41 56 310 32 14 / +41 56 310 31 51
EMAIL rivkin@psi.ch

Executive Secretary & Treasurer C. Petit-Jean-Genaz
AC Division
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CH-1211 Geneva 23, Switzerland
TEL/FAX +41 22 767 32 75 / 767 94 60
EMAIL christine.petit-jean-Genaz@cern.ch

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Chair P.H. Borcherds
Physics Department
The University of Birmingham
Edgbaston
UK-Birmingham B15 2TT, United Kingdom
TEL/FAX +44 121 475 3029 / 414 45 77
EMAIL p.h.borcherds@bham.ac.uk

Secretary A. Hansen
Instituut for Fysikk
Norges Teknisk-naturvitenskapelige Universitet
N-7491 Trondheim, Norway
TEL/FAX +47 73 59 36 49 / 73 59 33 72
EMAIL alex.hansen@phys.unit.no

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Chair D. Bulfone
ELETTRA
Sincrotrone Trieste
I-43012 Trieste, Italy
TEL/FAX +390 40 375 85 79 / 375 85 65
EMAIL bulfone@elettra.trieste.it

Vice-Chair A. Daneels
IT Division
CERN
CH-1211 Geneva 23
Switzerland
TEL/FAX +41 22 767 25 81 / 767 44 00
EMAIL axel.daneels@cern.ch

Treasurer J.-F. Gournay
Département de physique Nucléaire
CEA Saclay
Accélérateir Linéaire, DPH.N/AL
F-91191 Gif-sur-Yvette Cedex, France
TEL/FAX +33 1 69 08 70 32 / 69 08 81 38
EMAIL jgournay@cea.fr

Secretary I. S. Ko
Pohang University of Science & Technology
San 31, Hyoja-Dong
KR-790 784 Pohang, Korea
TEL/FAX +82 54 279 20 76 / 279 30 99
EMAIL isko@postech.ac.kr

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C.-Y. Yao, Hefei National Synchrotron Radiation Laboratory, China
J. Zhao, IHEP, China
Z. Zhiyuan, INR, China

History of Physics Group

Provisional Working Party
F. Bassani, Italian Physical Society, Bologna, Italy
EMAIL sif@sif.it
P. Borcherds, University of Birmingham, School of Physics and Astronomy, UK
EMAIL P.H.Borcherds@bham.ac.uk
E. Guyon, French Physical Society, Paris, France
EMAIL guyon@canoe.ens.fr
J. Vaagen, University of Bergen, Norway
EMAIL jans.vaagen@fi.uib.no

Physics for Development Group

Chair M. Chergui
Institut de Physique de la Matière Condensée
Faculté des Sciences, BSP
Université de Lausanne
CH-1015 Lausanne
Switzerland
TEL/FAX +41 21 692 3664 or 3678 / +41 21 692 3635
EMAIL Majed.Cherguiàipmc.unil.ch

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E. Lillethun, University of Bergen, Norway
H. van Regemorter, Observatoire de Paris- Meudon, France

Technology Group

Chair F. Bourgeois
M26900
CERN - LHC Division
CH-1211 Geneva 23, Switzerland
TEL/FAX +41 22 767 2041 / 767 6180
EMAIL francois.bourgeois@cern.ch

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Albanian Physical Society

Secretary General L. Cano
Physics Department
University of Tirana
AL-Tirana, Albania
TEL/FAX +355 42 39479 / -
EMAIL lcano@fshn.tirana.al

President A. Minxhozi
Albanian Physical Society
Diractorate of Scientific Research
Ministry of Education and Science
Durresi Street, 23
AL-Tirana, Albania
TEL/FAX +355 42 40468 / -
EMAIL magim@rotary.org.al

Vice-President P. Berberi
Polytechnic University of Tirana, Albania

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Armenian Physical Society

Secretary General E. Babakhanyan
Armenian Physical Society
Alikhanian Brothers St. 2
AM-375 036 Yerevan, Armenia
TEL/FAX +374 2 34 13 47 / 35 00 30
EMAIL eri@lx2.yerphi.am

President R. Avakian
See address of the Secretary General
EMAIL ravakian@hermes.desy.de

Austria

Austrian Physical Society

Secretariat G. Zobl-Kratschmann
c/o Institut für Isotopenforschung und Kernphysik
Universitaet Wien
Währinger Strasse 17
A-1090 Wien, Austria
TEL/FAX +43 1 4277-51203 / 4277-9512
EMAIL oepg-office@ap.univie.ac.at

President F.P. Netzer
Institut für Experimentalphysik
Karl-Franzens-Universität Graz
Universitätsplatz 5
A-8010 Graz Austria
TEL/FAX +43 316 380-5185 / 380-9816
EMAIL netzer@uni-graz.at

Vice-President W. Kutschera
Universitaet Wien, Austria

Treasurer H. Feichtinger
Karl-Franzens Universität Graz, Austria

Belarus

Belarusian Physical Society

Secretary E. A. Ershov-Pavlov
Institute of Molecular and Atomic Physics
National Academy of Sciences of Belarus
70, F. Skaryna Ave.
BY-220072 Minsk, Belarus
TEL/FAX +375 172 84 09 54 / 84 00 30
EMAIL ershov@imaph.bas-net.by

President P.A. Apanasevich
See address of the Secretary
TEL/FAX +375 172 84 06 54 / 39 31 31
EMAIL ifanbel@ifanbel.bas-net.by

Belgium

Belgian Physical Society

Secretariat J. Ingels
Belgisch Intituut voor Ruimte-Aëronomie
(Institut d'Aéronomie Spatiale de Belgique)
Editor Physicalia Info
Ringlaan 3
BE-1180 Ukkel, Belgium
TEL/FAX +32 2 373 03 78 / +32 2 374 84 23
EMAIL johan.ingels@bira-iasb.oma.be

General Secretary J. Ingels
See address of the Secretariat

President J. Indekeu
Katholieke Universiteit Leuven
Laboratorium voor Vaste-Stoffysica en Magnetisme
Celestijnenlaan 200d
BE-3001 Heverlee, Belgium
TEL/FAX +32 16 32 71 27 / +32 16 32 79 83
EMAIL joseph.indekeu@fys.kuleuven.ac.be

Vice-President P. Rudolf
Facultés universitaires Notre-Dame de la Paix, Belgium
Laboratoire Lise
TEL/FAX +32 81 72 52 37 / +32 81 72 45 95
EMAIL Petra.Rudolf@fundp.ac.be

Treasurer J. Hellemans
Katholieke Universiteit Leuven, Belgium
EMAIL jacqueline.hellemans@fys.kuleuven.ac.be

Bulgaria

Union of Physicists in Bulgaria

Secretariat S. Jordanova
Administrative Council of UPB
5, James Bourchier Blvd
BG-1164 Sofia, Bulgaria
TEL/FAX +359 2 62 76 60 / 96 25 276
EMAIL upb@phys.uni-sofia.bg

General Secretary T. Popov
See address of the Secretariat
EMAIL t.popov@phys.uni-sofia.bg

President M. Mateev
Union of Physicists in Bulgaria
Administrative Council
5 James Bourchier Blvd.
BG-1164 Sofia, Bulgaria
TEL/FAX +359 262 29 38 / 296 252 76
EMAIL mateev@phys.uni-sofia.bg

Vice-Presidents
A.G. Petrov, Bulgarian Academy of Sciences, Bulgaria
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V. Todorov, Medical Academy, Bulgaria

Croatia

Croatian Physical Society

Secretariat
Croatian Physical Society
Bijenicka 32
PO BOX 162 Zagreb, Croatia
TEL/FAX +385 1 460 55 55 / +385 1 468 03 36
EMAIL tajnik@hfd.hr

Secretary D. Bosnar
Faculty of Science of Croatia, Department of Physics
TEL/FAX +385 1 460 5577 / +385 1 468 0336
EMAIL bosnar@phy.hr

President G. Pichler
Institute of physics
PO BOX 304
Bijenicka 46
HR-10000 Zagreb, Croatia
TEL/FAX +385 1 469 8888 / +385 1 469 8889
EMAIL pichler@ifs.hr

Vice-President B. Pivac
Rudjer Boskovic Institute, Zagreb, Croatia
TEL/FAX +385 1 456 1111 / +385 1 468 0114
EMAIL pivac@rudjer.irb.hr

Treasurer Z. Vucic
Institute of Physics of Croatia
EMAIL vucic@ifs.hr

Czech Republic

Physical Section of the Union of Czech Mathematicians & Physicists

Secretariat J. Vitikova + A. Bernathova
Academy of Sciences of the Czech Republic
Institute of Physics
Na Slovance 2
CZ-180 40, Prague 8, Czech Republic
TEL/FAX +420 2 6605 2910 / -
EMAIL cieply@ujf.cas.cz

General Secretary A. Cieply
Nuclear Physics Institute, Rez near Prague, Czech Republic
TEL/FAX +420 2 6617 3284 / -
EMAIL cieply@ujf.cascz

President J. Dittrich
Nuclear Physics Institute, Rez near Prague, Czech Republic
TEL/FAX +420 2 2094 1147 / +420 2 2094 1130
EMAIL dittrich@ujf.cas.cz

Vice-Presidents
P. Chmela
Fakulta Strojni VUT, Czech Republic
D. Slavinska, Charles University, Czech Republic

Treasurer J. Masek
Czech Academy of Sciences, Institute of Physics
EMAIL masekj@fzu.cz

Denmark

Danish Physical Society

Secretary B. Andresen
University of Copenhagen
Physics Laboratory
Universitetsparken 5
DK-2100 Copenhagen, Denmark
TEL/FAX +45 35 32 18 18 / +45 35 32 04 60
EMAIL andresen@fys.ku.dk

President H. Bruus
Microelectronics Center
Technical University of Denmark
Building 345
DK-2800 Lyngby, Denmark
TEL/FAX +45 4525 6399 - +45 4525 5700 / +45 4588 7762
EMAIL bruus@mic.dtu.dk

Treasurer E.H. Pedersen
University of Aarhus
Institute of Physics and Astronomy
EMAIL horsdal@ifa.au.dk

Estonia

Estonian Physical Society

Secretariat
Estonian Physical Society
Tahe 4
EE-51010 Tartu, Estonia
TEL/FAX +372 7 383 034 / +372 7 375 520

President R. Jaaniso
Tartu University
Institute of Physics
Riia Str. 142
EE-51014 Tartu, Estonia
TEL/FAX +372 7 38 30 34 - +372 7 37 55 20 / +372 7 38 30 33
EMAIL jaaniso@fi.tartu.ee
Vice-Presidents
A. Kikas

directory

University of Tartu, Institute of Physics, Estonia
EMAIL kiku@fi.tartu.ee
P. Suurvarik
Tallinna Tehnikaulikool, Tallin, Estonia
EMAIL spaul@edu.ttu.ee

Finland

Finnish Physical Society

General Secretary E. Hänninen
University of Helsinki
Finnish Physical Society
PO BOX 64
FI-00014 Helsinki, Finland
TEL/FAX +358 9 191 50523 / +358 9 191 50553
EMAIL inphys@pcu.helsinki.fi

President O. Ikkala
Helsinki University of Technology
Department of Technical Physics and Mathematics, Optics and Molecular Materials PO BOX 2200
FI-02015 Hut, Finland
TEL/FAX +358 9 451 3154 - +358 40 520 1782 / +358 9 451 3155
EMAIL olli.ikkala@hut.fi

France

French Physical Society

Secretariat M.-F. Hanseler
Société Française de Physique - SFP
Agent Général
33, rue Croulebarbe
FR-75013 Paris, France
TEL/FAX +33 1 44 08 67 13 / +33 1 44 08 67 19
EMAIL sfp@sfpnet.org

General Secretary J. Teixera
See address of the Secretariat
EMAIL teix@llb.saclay.cea.fr

President E. Guyon
Societe Francaise de Physique - SFP
33, rue Croulebarbe
FR-75013 Paris, France
TEL/FAX +33 1 44 08 67 10 / +33 1 44 08 67 19
EMAIL guyon@pmmh.espci.fr

Vice-President E. Brezin
ENS, Département de Physique, Paris, France
TEL/FAX +33 1 44 32 34 95 / +33 1 47 07 13 99
EMAIL brezin@physique.ens.fr

Treasurer M. Gandais
See address of the Secretariat
EMAIL mgandais@club-internet.fr

Georgia

Georgian Physical Society

Secretariat N. Kevlishvili
Institute of Physics
Georgian Academy of Sciences
6 Tamarashvili Str.
GE-380077 Tbilisi, Georgia
TEL/FAX +995 32 395626 / -
EMAIL kev@iph.hepi.edu.ge

President J.L. Chkareuli
Institute of Physics
GE-380077 Tbilisi, Georgia
TEL/FAX +995 32 395626 / -
EMAIL jlc@physics.iberiapac.ge

Vice-Presidents
A. Gerasimov, Tbilisi State University, Georgia
Z. Saralidze, Georgian Academy of Sciences, Georgia

Germany

German Physical Society

Secretariat G. Tschäge
Deutsche Physikalische Gesellschaft e.V.
Hauptstr. 5
D-53604 Bad Honnef, Germany
TEL/FAX +49 030 2017 48-0 / +49 030 2017 48-50
EMAIL magnus@dpg-physik.de

General Secretary V. Haeselbarth
Deutsche Physikalische Gesellschaft e.V., Bad Honnef, Germany

President D. Basting
Lambda Physik Gmbh
Hans-Böckler Str. 12
D-37079 Göttingen, Germany
TEL/FAX +49 551 6938 100 / 6938 104
EMAIL basting@lambdaphysik.com

Vice-President A.M. Bradshaw
Max-Planck-Institut für Plasma Physik, Garching, Germany

Treasurer J.-E. Mosch
Deutsche Forschungsgemeinschaft, Bonn, Germany

Greece

Hellenic Physical Society

Secretariat M. Kazangi
Hellenic Physical Society
6 Grivaion Str.
GR-106 80 Athens, Greece
TEL/FAX +30 1 765 56 26 / -

General Secretary S. Vanikioti
Hellenic Physical Society, Greece

Contact A. Angelopoulos
EMAIL angel@phys.uoa.gr

President G. Papadopoulos
See address of the Secretariat
TEL/FAX +30 1 723 41 00 / 361 06 90

Vice-Presidents
P. Phildissis, Hellenic Physical Society, Greece
S. Tsitomeneas, Hellenic Physical Society, Greece

Treasurer K. Panourgias
Hellenic Physical Society, Greece

Hungary

Roland Eotvos Physical Society

Secretariat Z. Nagy
Fo u. 68.
H-1027 Budapest, Hungary
TEL/FAX +36 1 201 86 82 / 201 86 82
EMAIL mail.elft@mtesz.hu

General Secretary A. Kovach
Institute of Nuclear Research of the Hungarian Academy of Sciences, Hungary

Vice General Secretaries
S. Csajagi, Energetikai Szakkepzesi Intezet, Hungary
M. Molnar, JATE, Hungary
Z. Rajkovits, Eötvös Loránd University of Sciences, Hungary
G. Varga, Csik F.Alt.Iskola es Gimnazium, Hungary

President J. Gyulai
Research Institute for Technical Physics & Materials Science
P.O. Box 49
H-1525 Budapest, Hungary
TEL/FAX +36 1 392 22 24 / 392 22 26
EMAIL gyulai@mfa.kfki.hu

Vice-Presidents
J. Kopcsa, Hungary
L. Kovacs, Teacher Training College, Hungary
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Iceland

Icelandic Physical Society

Secretary G. Björnsson
Science Institute
University of Iceland
Dunhaga 3
IS-107 Reykjavik, Iceland
TEL/FAX +354 525 4800 / 8911

President H.P. Gislason
Science Institute
Dunhaga 3
IS-107 Reykjavik, Iceland
TEL/FAX +354 5 25 48 00 / 52 89 11
EMAIL haflidi@raunvis.hi.is

Treasurer J.T. Gudmundsson
University of Iceland, Iceland

Ireland

Royal Irish Academy

Secretariat P.J. Dempsey
Royal Irish Academy
19 Dawson Street
IRL-Dublin 2, Ireland
TEL/FAX +353 1 676 25 70 / 676 23 46
EMAIL p.dempsey@ria.ie

Secretary G. O'Sullivan
Royal Irish Academy, Ireland

President M. Ryan
National Committee for Physics
Royal Irish Academy
19 Dawson Street
IRL-Dublin 2, Ireland
TEL/FAX +353 1 608 23 60 / 608 23 03
EMAIL admin@ria.ie

Israel

Israel Physical Society

Secretary T. Ben-Gai
Ben-Gurion University
Department of Physics
PO BOX 653
IL-84105 Beer-Sheva, Israel
TEL/FAX +972 8 646 1645 / +972 8 647 2904
EMAIL bengai@hemda.org.il

President E. Ben-Jacob
School of Physics and Astronomy, Sackler Faculty of Exact Sciences
Tel-Aviv University
IL-69978 Tel Aviv, Israel
TEL/FAX +972 3 6425 787 / +972 3 6422 979
EMAIL eshel@albert.tau.ac.il

Vice-President J. Adler
Technion, Haifa, Israel
EMAIL phr76ja@tx.technion.ac.il

Treasurer L.G. Benguigui
Technion, Department of Physics, Haifa, Israel
EMAIL ssgilles@techunix.technion.ac.il

Italy

Italian Physical Society

Secretariat B. Alzani
Società Italiana di Fisica
Via Castiglione, 101
I-40136 Bologna, Italy
TEL/FAX +39 051 33 15 54 / 58 13 40
EMAIL sif@sif.it

President G.F. Bassani
See address of the Secretariat

Vice-President L. Cifarelli
Universita' di Salerno, Italy

Honorary President R.A. Ricci
Laboratori Nazionali di Legnaro (INFN), Italy

Latvia

Latvian Physical Society

Secretariat O. Docenko
University of Latvia
Department of Physics
Zellu Str. 8
LV-1002 Riga, Latvia
TEL/FAX +371 7033 793 / -
EMAIL odocenko@latnet.lv

President I. Bersons
See address of the Secretariat
TEL/FAX +371 7229 747 / -
EMAIL bersons@latnet.lv

Vice-President G. Liberts
Daugavpils Pedagogical University, Latvia
TEL/FAX +317 9276 061 / -
EMAIL liberts@latnet.lv

Lithuania

Lithuanian Physical Society

Secretariat
Lithuanian Physical Society
Lietuvos Fiziku Draugija
A. Gostauto 12
LT-2600 Vilnius, Lithuania
TEL/FAX +370 2 62 06 68 / +370 2 61 84 64
EMAIL lfd@itpa.lt

Secretary A. Bernotas
Institute of Theoretical Physics and Astronomy
Academy of Sciences of Lithuania
EMAIL bernotas@itpa.lt

President Z. Rudzikas
State Institute of Theoretical Physics and Astronomy
Academy of Sciences of Lithuania
A. Gostauto 12
LT-2600 Vilnius, Lithuania
TEL/FAX +370 5 262 0668 / +370 5 212 4694
EMAIL tmkc.plls@wllb.lt

Treasurer R. Sadzius
Vilnius University, Lithuania
EMAIL sadzius@delfi.lt

Vice-Presidents
D. Butkus, Vilnius University, Lithuania
EMAIL butkus@ar.fi.lt
G. Dikcius, Vilnius University, Lithuania
EMAIL gintaras.dikcius@ff.vu.lt
A. Piskarskas, Vilnius university, Lithuania
EMAIL algis.piskarskas@ff.vu.lt
A. Sileika, Lithuanian Academy of Sciences, Lithuania
EMAIL secgenas@kll.mii.lt

Macedonia

Society of Physicists of Macedonia

Secretariat
Society of Physicists of Macedonia
Institute of Physics
St. Cyril and Methodius University
MK-91000 Skopje, Macedonia
TEL/FAX +389 9111 70 55 / 22 81 41
EMAIL fizmak@iunona.pmf.ukim.edu.mk

Secretary N. Stojanov
Faculty of Natural Sciences and Mathematics, Macedonia

President B. Veljanoski
See address of the Secretariat
EMAIL blagoj@iunona.pmf.ukim.edu.mk

Treasurer A. Kanevce
Department of Physics, Macedonia

The Netherlands

The Netherlands' Physical Society

Secretariat A. Jelles
The Netherlands' Physical Society
Nederlandse Natuukundige Vereniging
PO BOX 302
NL-1170 AH Badhoeverdorp, The Netherlands
TEL/FAX +31 20 658 02 28 / 659 24 77
EMAIL a.jelles@nnv.nl

Secretary E.W.A. Lingeman
c/o NIKHEF, The Netherlands
EMAIL ed@nikhef.nl

President H. E. A. van den Akker
Kramers Laboratorium, Prins Bernardlaan 6
NL-2628 BW Delft The Netherlands
TEL/FAX +31 15 27 81 400 / 27 82 838
EMAIL vdakker@klft.tn.tudelft.nl

Treasurer J. Konijn
NIKHEF, The Netherlands
EMAIL j.konijn@nikhef.nl

Norway

Norwegian Physical Society

Secretary H. Bruvoll
Department of Physics
University of Oslo
POB 1048
N-0316 Oslo, Norway
TEL/FAX +47 22 85 64 26 / 22 85 64 22
EMAIL heidib@fys.uio.no

President S. Stapnes
Department of Physics
University of Oslo
POB 1048 Blindern
N-0316 Oslo, Norway
TEL/FAX +47 22 85 50 63 / 22 85 64 22
EMAIL steinar.stapnes@fys.uio.no

Poland

Polish Physical Society

Secretariat K. Zakowicz
Polish Physical Society
Main Board
ul. Hoza 69
PL- 00-681 Warsaw, Poland
TEL/FAX +48 22 621 26 68 / +48 22 621 26 68
EMAIL ptf@fuw.edu.pl

Secretary General A. Leliwa-Kopystynska
Polish Academy of Sciences, Faculty of Physics
Institute of Experimental Physics
ul. Hoza 69
PL-00-681 Warsaw, Poland
TEL/FAX +48 22 553 23 46 / +48 22 625 64 06
EMAIL akopyst@fuw.edu.pl

President M. Kolwas
Polish Academy of Sciences, Institute of Physics
International Postgraduate Studies
al. Lotnikow 32/46
PL-2668 Warsaw, Poland
TEL/FAX +48 22 847 09 17 / +48 22 843 09 26
EMAIL kolwas@ifpan.edu.pl

Vice-Presidents
K. Chalasinska-Macukow, Warsaw University, Poland
EMAIL kmacukow@mimuw.edu.pl
R. Kulessa, Jagiellonian University, Poland
EMAIL kulessa@if.uj.edu.pl

Treasurer M. Kowalski
Warsaw University of Technology, Institute of Physics
EMAIL marko@if.pw.edu.pl

Portugal

Portuguese Physical Society

Secretariat M.J. Couceiro da Costa
Sociedade Portuguesa de Fisica
Av. da Republica, 37-4°
PT-1050-187, Lisboa, Portugal
TEL/FAX +351 217 993 665 / +351 217 952 349
EMAIL mjose@spf.pt

General Secretary A. Barroso
Universidade de Lisboa, Depto. Fisica, Portugal
TEL/FAX +351 21 790 48 23 / +351 21 795 42 88
EMAIL barroso@cii.fc.ul.pt

Secretary M. Conceiçao Abreu e Silva
Universidade do Algarve, Faculdade de Ciencias, Faro, Portugal
TEL/FAX +351 289 800 987 / -
EMAIL mabreu@ualg.pt

President J.D. Urbano
Universidade de Coimbra
Departamento de Fisica
Rua Larga
PT-3004-516, Coimbra, Portugal
TEL/FAX +351 39 410 600 / -
EMAIL urbano@teor.fis.uc.pt

Vice-President M. Fiolhais
Universidade de Coimbra, Faculdade de Ciencias e Tecnologia, Portugal
EMAIL t.manuel@teor.fis.uc.pt

Treasurer & Local Coordinator M.A. Pedro de Jesus
Universidade de Lisboa, Portugal
EMAIL apjesus@cii.fc.ul.pt

Romania

Romanian Physical Society

Secretariat A. Anitoaiei
Institute of Physics and Nuclear Engineering (INPE)
POB MG-6
R-Bucharest-Magurele, Romania
TEL/FAX +40 1 4042303 / 4042311 or 4231472

General Secretary D. Grecu
Polytechnic University, Romania

President A. Calboreanu
Tandem Laboratory
Institute of Physics and Nuclear Engineering
POB MG-6
R-Bucharest-Magurele, Romania
TEL/FAX +40 1 4042303 / 4042311 or 4231472
EMAIL calbo@ifin.nipne.ro

Vice-President V. Grecu
Faculty of Physics, Romania

Russia

United Physical Society of the Russian Federation

Secretary A. P. Kovaleva
National Committee of Russian Physicists
General Physics & Astronomy Dept.
Russian Academy of Sciences
32 a, Leninsky Prospect
RU-117993 Moscow, Russia
TEL/FAX +7 095 938 54 54 / 938 17 14
EMAIL alina@gpad.ac.ru

Secretary General V.A. Zayats
See address of the Secretariat
TEL/FAX +7 095 938 5500 / 938 17 14
EMAIL zayats@gpad.ac.ru

directory

President L.V. Keldysh
See address of the Secretariat
TEL/FAX +7 095 938 5454 / 938 17 14
EMAIL keldysh@gpad.ac.ru

Vice-President S.N. Bagayev
Siberian Branch of the Russian Academy of Sciences, Russia
EMAIL bagayev@laser.nsc.ru

Slovakia

Slovak Physical Society

Secretariat
Slovak Physical Society
Slovak Academy of Sciences
Dubravska cesta 9
SK-842 28 Bratislava, Slovak Republic
EMAIL sfs@savba.sk

Secretary General D. Krupa
Slovak Academy of Sciences
Institute of Physics
Dubravska cesta 9
SK-842 28 Bratislava, Slovakia
TEL/FAX +421 2 5941 0514 / +421 2 5477 6085
EMAIL krupa@savba.sk

President J. Stanicek
Faculty of Mathematics, Physics and Informatics
Comenius University
mMlynska dolina
SK-842 15 Bratislava, Slovakia
TEL/FAX +421 2 6029 5454 / +421 2 6542 5882
EMAIL stanicek@fmph.uniba.sk

Vice-President M. Reiffers
Institute of Experimental Physics, Kosice, Slovakia
EMAIL reiffers@saske.sk

Treasurer E. Illekova
Slovak Academy of Sciences, Institute of Physics, Bratislava, Slovakia
EMAIL fyziille@savba.sk

Slovenia

Society of Mathematicians, Physicists and Astronomers of Slovenia

Secretariat J. Krusic
Department of Mathematics
University of Ljubljana
Jadranska 19
SI-1000 Ljubljana, Slovenia
TEL/FAX +386 1 476 65 59 / 12517281

Secretary J. Krusic
See address of Secretariat

President Z. Trontelj
See address of Secretariat
TEL/FAX +386 1 476 65 82 / 12517281
EMAIL zvonko.trontelj@fiz.uni-lj.si

Vice-President I. Musevic
University of Ljubljana, Slovenia

Treasurer A. Jaklic
University of Ljubljana, Slovenia

Spain

Spanish Royal Society of Physics

Secretariat C.Z. Exposito
Real Sociedad Espanola de Fisica
fFaculdad de Fisica
Universidad Complutense de Madrid
ES-28040 Madrid, Spain
TEL/FAX +34 1 394 43 59 - +34 1 394 43 61 / +34 1 543 38 79
EMAIL rsef@fis.ucm.es

Secretary General M. Shaw Martos
Faculdad de Ciencias, Dpto. de Fisica de los Materiales, Madrid, Spain
EMAIL mshaw@ccia.uned.es

President G. Delgado Barrio
Instituto de Fisica Fundamentale
Serrano 123 - CSIC
ES-28006 Madrid, Spain
TEL/FAX +34 9 1 585 51 96 / +34 9 1 585 53 98
EMAIL gerardo@fam77.imaff.csic.es

Vice-Presidents
J.M. Fernandez de Labastida, Subdirector Gral. de Proyectos de Investigacion, Madrid, Spain
EMAIL labasti@fpaxp1.usc.es
A. Ferrer Soria, IFIC-Universidad de Valencia, Burjassot (Valencia), Spain
EMAIL antonio.ferrer@ific.uv.es.
C.F. Pineda, Universidad Complutense de Madrid, Spain
EMAIL fdezpine@fis.ucmes

Treasurer V.R. Velasco Rodriguez
Instituto de Ciencias de Materiales, Cantoblanco (Madrid), Spain
EMAIL vrvr@icmm.csic.es

Sweden

Swedish Physical Society

Secretariat
Swedish Physical Society
Manne Siegbahn Laboratory
Frescativägen 24
S-104 05 Stockholm, Sweden
EMAIL sfs@msi.se

Secretary H. Danared
Manne Siegbahn Laboratory
Frescativägen 24
SE-104 05, Stockholm, Sweden
TEL/FAX +46 8 161 038 / +46 8 158 674
EMAIL danared@msi.se

President B. Jonson
Chalmers University of Technology and Göteborg University
Department of Experimental Physics
SE-412 96, Göteborg, Sweden
TEL/FAX +46 31 772 32 62 / +46 31 772 32 69
EMAIL bjn@fy.chalmers.se
EMAIL sfs@msi.se

Treasurer K.G. Rensfelt
Stockholm University, Manne Siegbahn Laboratory, Sweden
EMAIL rensfelt@msi.se

Switzerland

Swiss Physical Society

Secretariat S. Albietz
Swiss Physical Society
SPG Büro
Universitaet Basel
Klingelbergstrasse 82
CH-4056 Basel, Switzerland
TEL/FAX +41 61 267 37 15 / +41 61 267 37 84
EMAIL sps@unibas.ch

Secretary J.-M. Bonard
IPN - SB
EPFL
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 693 44 10 / +41 01 693 36 04
EMAIL jean-marc.bonard@epfl.ch

President J.Ph. Ansermet
EPFL -IPE Ecublens
Institut de Physique Expérimentale
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 693 33 39 / +41 21 693 3604
EMAIL jean-philippe.ansermet@epfl.ch

Treasurer T. Gyalog
Universität Basel, Institut für Physik, Pharmazentrum, Switzerland
EMAIL tibor.gyalog@unibas.ch

Turkey

Turkish Physical Society

General Secretary S. Kartal
University of Istanbul
Department of Physics
TR-34459 Vezneciler-Istanbul, Turkey
TEL/FAX +90 212 511 84 80 (ext. 1262) / +90 212 519 08 34
EMAIL sehban@istanbul.edu.tr
EMAIL sehban@fnal.gov

President M.N. Erduran
University of Istanbul
Department of Physics
TR-34459 Vezneciler-Istanbul, Turkey
TEL/FAX +90 212 511 8480(ext. 1277) / +90 212 519 0834
EMAIL erduran@nucleus.istanbul.edu.tr

Vice-President E.A. Bogazici
University of Istanbul, Bebek-Istanbul, Turkey
EMAIL engin@ocean.phys.boun.edu.tr

Treasurer I. Karabay
Yildiz Technical University, Davutpasa-Istanbul, Turkey
EMAIL karabay@yildiz.edu.tr

Ukraine

Ukrainian Physical Society

Executive Secretary C.V. Usenko
Taras Shevchenko National Kyiv University
Faculty of Physics
Academic Glushkova Ave. 6
UA-3680 Kyiv, Ukraine
TEL/FAX +380 44 266 3060 / +380 44 266 4036
EMAIL usenko@phys.univ.kiev.ua

President I.O. Vakarchuk
Ivan Franko National University of Lviv
Department of Theoretical Physics
1, Universitetska Str.
UA-79000 Lviv, Ukraine
TEL/FAX +380 322 74 1262 / +380 322 97 1668
EMAIL presiden@ups.kiev.ua

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EMAIL stakhira@wups.kiev.ua

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The Institute of Physics

Secretariat
The Institute of Physics
IOP
76 Portland Place
UK- London W1B 1NT, England
TEL/FAX +44 20 7470 4800 / +44 20 7470 4848
EMAIL physics@iop.org

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See address of the Secretariat
EMAIL julia.king@iop.org

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See address of the Secretariat
EMAIL physics@iop.org

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EMAIL physics@iop.org

Contact P. Melville
See address of the Secretariat
EMAIL peter.melville@iop.org

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EMAIL tony.scott@ucd.ie

Yugoslavia

Yugoslav Physical Society

Secretariat
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Pregrevica 118
YU-11080 Beograd-Zemun, Yugoslavia
TEL/FAX +381 11 3160260 ext. 166 / 3162190
EMAIL jdf@phy.bg.ac.yu

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Pregrevica 118
YU-11080 Beograd-Zemun, Yugoslavia
TEL/FAX +381 11 3160260 ext. 160 / 3162190
EMAIL markusev@phy.bg.ac.yu

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Pregrevica 118
YU-11080 Beograd-Zemun, Yugoslavia
TEL/FAX +381 11 3160598 / 3160531
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TEL/FAX +49 030 6392 2999 / +49 030 6392 2990

CEA Saclay
Mrs Gillot
FR-91191 Gif-sur-Yvette, France
TEL/FAX +33 1 69 08 24 73 / +33 1 69 08 27 07

CERN
C. Jarlskog
CH-1211 Geneva 23, Switzerland
TEL/FAX +41 22 767 24 14 / +41 22 767 67 60
EMAIL cecilia.jarlskog@cern.ch

CNR
Consiglio Nazionale delle Richerche
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Piazza dell' Ateneo 1
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DESY
Director
Notkestrasse 85
DE-22603 Hamburg, Germany
TEL/FAX +49 40 89 98 3100 / +49 40 89 98 3282

DLR
B.P. Feuerbacher
Der Vorstand
Postfach 90 60 58
DE-51126 Köln, Germany
TEL/FAX +49 2203 60 10 / +49 2203 61 768
EMAIL berndt.feuerbacher@dlr.de

ECN
R. Blackstone
Researchcentrum
Postbus 1
NL-1755 ZG Petten, Netherlands
TEL/FAX +31 224 564 949 / +31 224 564 5480

EFDA - JETS
J. Pamela
Culham Science Centre K1-1-96
UK-Abington OX14 3DB, United Kingdom
TEL/FAX +44 1235 52 88 22 / +44 1235 46 44 00

EPFL - CRPP
M.Q. Tran
Association EURATOM - Confédération Suisse
PPB-ECUBLENS
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 603 5474 / +41 21 693 5176
EMAIL minhquang.tran@epfl.ch

EPFL-Ecublens - IPE
J.P. Ansermet
Département de Physique
CH-1015 Lausanne, Switzerland
TEL/FAX +41 21 693 33 39 / +41 21 693 3604
EMAIL jean-philippe.ansermet@epfl.ch

ESA
D. Southwood
Director of Scientific Programme
8-10, rue Mario Nikis
FR-75738 Paris Cedex 15, France
TEL/FAX +33 1 53 69 71 07 / +33 1 53 69 72 36
EMAIL David.Southwood@esa.int

ESRF
W.G. Stirling
BP 200
FR-38043 Grenoble Cedex, France
TEL/FAX +33 4 76 88 20 30 / +33 4 76 88 24 18
EMAIL stirling@esrf.fr

ETH Zürich - EHT-Hönggerberg
M. Landolt
CH-8093 Zürich, Switzerland
TEL/FAX +41 1 633 2586 / +41 1 633 1106
EMAIL Landolt@phys.ethz.ch

FIZ
G.F. Schultheiss
Hermann-von-Helmholtz-Platz 1
DE-76344 Eggenstein-Leopoldshafen, Germany
TEL/FAX +49 7247 808 100 / +49 7247 808 114
EMAIL FIZKA@fiz-Karlsruhe.de

FNRS
M.-J. Simoen
Rue d'Egmont, 5
BE-1050 Brussels, Belgium
TEL/FAX +32 2 504 92 11 (centrale) / +32 2 504 92 92
EMAIL mjsimoen@fnrs.be

FOA
H. Nordstroem
Division 21
SE-172 90 Stockholm, Sweden
TEL/FAX +46 8 663 1500 / +46 8 628 8903
EMAIL hakan.nordstroem@sto.foa.se

FOM
K.H. Chang
Postbus 3021
NL-3502 GA, UTRECHT, Netherlands
TEL/FAX +31 30 600 1226 / +31 30 601 4406
EMAIL hans.chang@fom.nl

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TEL/FAX +49 2461 61 3000 / +49 2461 61 2525
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GSI
Wissenschaftlicher Direktor
Postfach 11 05 52
DE-64220 Darmstadt, Germany
TEL/FAX +49 6159 71 0 / +49 35 97 85

Hahn-Meitner-Institut Berlin GmbH (HMI)
M. Steiner
Scientific Director
Glienicker Str. 100
DE-14109 Berlin, Germany
TEL/FAX +49 30 8062 2762 / +49 30 8062 2047
EMAIL steiner@hmi.de

Haldor Topsoe A/S
H. Topsoe
Research and Development Division
Nymollevej 55
DK-2800 Lyngby, Denmark
TEL/FAX +45 45 27 2458 / +45 22 75 4458 (mobile)
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PO Box 40
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FR-38042 Grenoble Cedex 9, France
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IMEC – Interuniversity Micro-Electronics Entre
G. Declerck
Kapeldreef 75 Leuven, Belgium
TEL/FAX +32 16 28 12 11 / +32 16 22 94 00

INFM – Istituto Nazionale per la Fisica della Materia
F. Toigo
President
Corso F. Perrone, 24
IT-16152 Genova, Italy
TEL/FAX +39 10 6598 750 / 30 +39 10 6506 302
EMAIL toigo@infm.it
EMAIL esteri@infm.it

INFN – Istituto Nazionale di Fisica Nucleare
E. Iarocci
CP 56
IT-00044 Frascati, Italy
TEL/FAX +39 06 940 35 73 / +39 06 940 35 82
EMAIL iarocci@inf.infn.it

Institut "Jozef Stefan"
J. Slak
PO Box 3000
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Mekelweg 15
NL-2629 JB, Delft, Netherlands
TEL/FAX +31 15 278 5052 / +31 15 278 6422
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directory

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B. Cagnac
Z.I. de Courtaboeuf
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FR-91944Les Ulis Cedex, France
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MPI – Max-Planck-Insitut fuer Plasmaphysik
H.-S. Bosch
Scientific and Technical Office
Postfach 1533
D-85740 Garching, Germany
TEL/FAX +49 89 32 99 2112 / +49 89 32 99 1001
EMAIL bosch@ipp.mpg.de

MPI – Max-Planck-Insitut fuer Quantenoptik
K.-L. Kompa
Laser Chemistry Division
Ludwig-Prandtl-Str. 10
DE-85748 Garching, Germany
TEL/FAX +49 89 329 05 07 / +49 89 32 90 52 00

NORDITA
J. Vaagen
University of Bergen, Physics Insitute
Allegaten 55
NO-5007 Bergen, Norway
TEL/FAX +47 55 58 27 24 / +47 55 58 94 40
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Braunschweig und Berlin
E.O. Göbel
Postfach 33 45
DE-38023 Braunschweig, Germany
TEL/FAX +49 531 592 1000 / +49 531 592 1005
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RISO National Laboratory
J. Kjems
PO BOX 49
DK-4000 Roskilde, Denmark
TEL/FAX +45 4677 4601 / +45 4677 4607
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SIA – Societa Italiana Avionica
M. Panighini
Via G. Servais 125
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SIEMENS AG
D. Theis
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Euro entrepreneurs set to fuel the knowledge based economy

Brian More, Business Development Manager
School of Physics and Astronomy, University of Birmingham, Edgbaston B15 2TT

Collaboration has always played a major role in progressing scientific discovery through to commercial products, likewise the most successful individuals and companies are those active within large networks. The aim of the European Research Area is to encourage efficient technology transfer from the more focussed research programmes in Framework Programme 6(FP6) to commercial products, ultimately for sustainable wealth creation. This will be achieved by the provision of larger networks, integrating the business community at the heart of these networks and support for technology clusters. Figure 1 shows the infrastructure matrix to be implemented later this year. This article will examine just one facet of commercially driven research, that is the implications for the academic university physicist who faces the prospect of a spin-out company opportunity and what support is at hand to achieve profitability for all concerned.

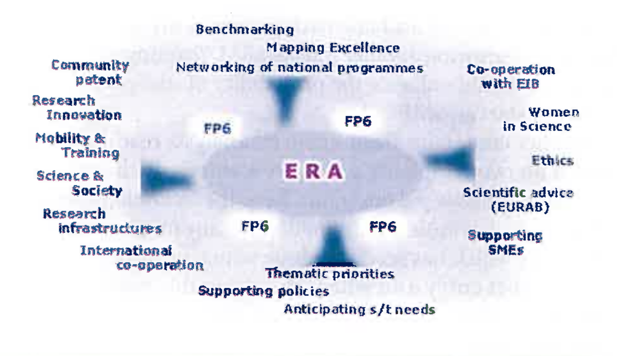
European Universities in the twenty first century are adapting to mounting social and economic pressures to realise financial gain from their research portfolios. This shift from purely scientific research, teaching and education to high added-value continuing professional development courses for industry, spin-out companies and license-revenue streams incites polarisation of views within academia. On the one hand universities will continue to deliver fundamental science purely from curiosity-driven research to increase global understanding, funded through research grants; on the other hand third phase activities will need to generate additional income from commercial exploitation. The physicist must achieve an acceptable balance between the usual research and student education and ensuring commercial success of the university. In the case of physics, where student numbers are still in decline the pressures are for department survival at many universities.

From the social viewpoint, government-funded research has to be judged against alternative options, hospitals and transport schemes for example where value for money is demanded. This commercial/educational debate is an emotive one throughout Europe and will continue as universities adapt to the new knowledge driven economy.

One definite benefit from more commercially driven research is seen in the increased transferable skills of university researchers, making the transition to/from industry that much easier.

Most large research and technology focused corporations have business functions available to support the research scientist, legal, patent attorneys, information retrieval services, market analysts, marketing, sales, after sales services etc. A research project has clearly defined targets and deliverables with product development metrics imposed to ensure an ultimate conclusion, mainly success or failure at different product 'gates'. What then is best practice in starting a spin-out company where these support functions are not readily available, and fundamental research has not had rigorous product focus?

European scientists have an excellent track record in publishing peer-reviewed papers that are widely cited. However, you have to look across the Atlantic to find the lead in exploitation. In a field like nanotechnology, expected to commercially emulate the success of the semiconductor and biotechnology sectors, the US started 225 new technology based SME's last year compared to



▲ **Fig. 1:** A framework for commercial as well as scientific success the FP6 model encourages Small and Medium Enterprise (SME) growth within an ever expanding European Research Area[1].

▼ **Table 1:** Entrepreneur's Start-up Company Check List

- An absolute mission to create a new force in your chosen technology
- A balanced high quality management team embracing technical, commercial and marketing skills in a related industry
- A track record of success in the targeted industry and technology
- Selection of an attractive high growth rate market segment
- Evidence that the project has a 'significant and defensible competitive advantage' against existing and/or new competitors
- A working prototype of the technology/product application
- Ownership of the key Intellectual Property Rights
- A significant commitment of personal resources by the entrepreneur and his/her team
- A comprehensive (25 pages max) and well thought out Business Plan
- TRUE GRIT – An implacable and unreasonable determination to succeed against all odds

120 across Europe[2]. The ratio is similar to the perceived risk from a European survey carried out on about 8200 entrepreneurs which showed 45% of Americans would take a risk on starting an SME compared to only 27% of Europeans[3]. The risk is coupled to the fact that finance is easier to attract in the US; in the mid-to-late nineties the US spent on average 0.11% of GDP on venture capital funding of high technology companies, compared to only 0.03% in the U.K.[4] In addition the US had extra incentives for entrepreneurs through new regulations governing start-up companies and tax incentives.

In learning from the US, nearly every European university now has an office of technology transfer, dedicated to supporting new ventures, and many have access to 'seed corn' funds enabling product demonstrators to be developed. The important factor for success is protection of the intellectual property stemming from research, usually as either a patent or registered design. Many Universities now fund development projects from license deals and have patent attorneys, lawyers and financial advisors in house.

The first step from the laboratory is to your office of technology transfer, where patent and commercial advice is at hand. Remember you can't do everything yourself.

So what is the characteristic of the successful entrepreneur? Every high growth SME has a different story to tell about the route, but generally the character of the founder is crucial to the success. The main attributes and skills for the entrepreneur are

- Strength as a Team Player
- Trustworthiness
- Excellence in communication
- Breadth of scientific understanding
- Tenacity
- Determination
- Self-Confidence
- Attention to detail
- Desire to make Money

If any doubt exists that starting your own company is the right solution then a better alternative strategy is to license out the technology; out of every 100 start-up high technology companies 40 will fail within 3 years, 60 within 10 years and 4 will contribute 50% to the total wealth and job creation[5].

Once the decision to start a new high-tech company has been made you will need a well-structured and defensible business plan, no more than 25 pages in length. This will be a working document guiding your company's development.

The most likely business plans to be funded have key factors, protected IP, a very experienced and respected management team with a track record in the chosen industry and a clear vision of the company's growth plans. The right team is crucial to success. JD Albert founder of the Massachusetts based E Ink Corporation considers the right people ten times more important than the technology, a sentiment echoed by corporate investors[6]. When defending the business plan a thorough knowledge of the competition is essential, especially a realistic prediction of your market share. One of the UK.'s successful start-ups is Oxford Instruments, emanating from the physics department at Oxford University. Former chairman and CEO Sir Peter Williams is quoted as saying, "Basically we had the right products at the right cost for the right people at the right time"[6].

Even before the 11th September terrorism in the US last year an economic slow down had begun. Fortunately the tide has now turned with venture capital funds targeting high tech companies again, and more importantly on both sides of the Atlantic a wealth of very experienced and talented executives are looking for the challenge of growing another Intel or IBM. Teaming up with these executives would enhance the probability of success in securing finance to start an SME[7],[8].

Another complaint from financial analysts reading business plans is an over emphasis on 'clever science' which leaves them with many unanswered questions. Keep the technology section to a minimum. A winning combination for any investor is a simple technology which has several unique selling positions, few barriers to market entry and where the attainable market share is expected to show double-figure year-on-year growth. Table 1 below has some 'common sense' practical advice for entrepreneurs, a checklist of attributes recommended by the CEC. Table 2 lists the funding options for technology development at the different stages of technology maturity and Table 3 the differences in 4 principle routes for funding innovation in Europe[5]. An investor

(i) Research Stage • **Funding in the form of non-reimbursable grants** - Very unlikely to get Banks or Equity Investors interested at this early stage • **Public Sector** - National Governments - Regional Authorities - European Commission • **Corporations** - Industrial/Commercial Companies - Industrial Research Associations - Charities	**(ii) Development Stage** • **To build a prototype or pilot plant to demonstrate feasibility** • **Public Sector and Corporate Sector** • **Seed Capital / Risk Capital** - Pre start up investment in technology - Loans convertible to equity if company formed • **Venture Capital** - May be interested where an existing company seeks additional finance for a specific project
(iii) Start Up Stage • **Remains the most difficult stage to finance** • **Business Angels** - Provision of start up equity finance, also hands on advice and help - Very well networked • **Venture Capital** - Equity finance for start-up, experienced and contribute to management assistance • **Public Sector** - Could cover start-up and capital costs, especially if employment opportunities are seen • **Corporations** - Industrial or commercial firms seeking a 'window' on developments, could wish to buy the new company at a later stage	**(iv) Exploitation Stage** • **Company in commercial operation and looking to expand** • **As for start-up stage** • **Initial Public Offering (IPO)considered** - Management Buy Out (MBO) - Management Buy In (MBI) • **New Markets considered** - AIM - NASDAQ - EASDAQ - Nouveau Marche - Neuer Markt

▲ **Table 2:** Raising Finance Options by Technology Maturity will allocate funds sufficient to enable the company to succeed; a common problem for new entrepreneurs is to underestimate the finance required, and the time to demonstrate the technology. When your proposition is funded you will have a targeted and focused business plan to follow, often with milestone payments made on delivery of targets.

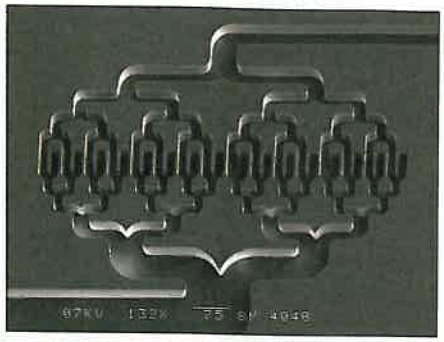
One way to increase the probability of meeting business targets is to locate your embryonic company in an incubator, or downstream factory, where clusters of like minded entrepreneurs can benefit from economy of scale. Clusters of start-ups in nanotechnology are encouraged in the Grenoble conurbation in France and proposed for the West Midlands of England for example. The cluster effect attracts excellent people and international finance. Once a region or department has made the commitment to develop a high technology cluster then financial assistance is often forthcoming for capital items and preferential rent terms, especially if this creates new employment.

▼ **Table 3:** Funding Option Matrix

(i) Friends and Family Funding • 'helping hand' rather than serious investment • Cannot be relied upon for follow up finance • May not have useful commercial contacts • Generally less than €10,000	**ii) Banks** • Provide the usual banking services • Loans and loan guarantees from a few thousand to millions of € • Investment Services • Quick decisions • Security required for loans • Interest will be charged on outstanding balances • 'Risk Averse'
(iii) Venture Capital Funding • Seek investments in firms with high-growth possibilities • Not usually interested below €300,000 • Slow decisions but very thorough – due diligence • Add value, not just financial assistance • No outflow of cash in interest on loans or dividends to investors before exit • Equity share • No security • No interest • Some loss of control • A seat on the Board for the investor • Strong financial discipline • Sharing the profits on realising the investment	**(iv) Business Angels** • Individuals of 'high net worth' • 75% invest between €20,000 and €200,000 or higher on syndicated investments • Usually invest locally and in projects they understand • Quick decisions • Likely to take a 'hands on' approach to their investment • Equity share • No security • No interest • Some loss of control • A seat on the Board for the investor • Strong financial discipline • Sharing the profits on realising the investment

(Further information [7],[8])

So how is Europe positioned with respect to high technology start-ups, where are the new growth areas and how should we approach the financiers looking for the 'killertechnology'? Electronics is still a growth area and in particular the optoelectronics arena gearing up to deliver fibre to the home. Nanotechnology has gained a lot of commercial interest in the last few years, however, venture capitalists are wary of leaping in with risk capital in the same way as witnessed in the dot-com boom. Any link to the medical diagnostics market is strongly favoured; an ageing population using reliable self diagnostics will reduce the burden on the medical profession. The development of any early biological markers to disease will attract funding, coupled to controlled drug delivery being the ultimate aim.



▲ **Fig. 2: Lab on a chip.** The convergence of many scientific disciplines to achieve multiple compound analyses on a single microchip will be a commercial winner.

Physicists have been credited with major contributions to our standard of living and welfare, from fuelling the electronics industry to enabling keyhole surgery, through instruments operating in space to inventing the World Wide Web. A financial times survey in the year 2000 identified 18 out of the world's top 25 businesses were physics based. There are many examples of companies in the top 100 who started from humble beginnings to dominate in their business sector, Intel, Microsoft, Cisco, Hewlett Packard to name but a few. Just as at the beginning, innovation and flexibility are the attributes to staying competitive.

University based physicists now have the support networks for commercial as well as academic success. Take a long hard look at your results, get fired up by the possibilities and visit your technology transfer office. It could be the gateway to an exciting career in your own business.

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Two independent-minded physicists from opposite ends of Europe issue a challenge to orthodoxy in teaching and research.

Room for error: *a Danish view*

Interview by Jens Olaf Pepke Pedersen, Danish Center for Earth System Science

There are many examples showing that a physics background has led to a successful career in either academia, industry, or government. It is more exceptional however, to find someone who has had a successful career in all three. Professor Ove Poulsen is one such example. Working his way through postdoc and associate professor positions, he became a full professor in optical physics at the University of Aarhus, Denmark, in 1986. In 1991, he moved to the Technical University of Denmark to become managing director at the Microelectronics Centre. In four years he built a research centre with more than 100 employees with the participation of a number of large Danish companies. In 1995, he was then appointed Director of Research Policy in the Danish Ministry of Research and Information Technology. Two years ago, he moved to industry and became Executive Director for NKT Research.

Professor Ove Poulsen is 56 years old and well known to many members of the EPS, where he served 1990-96 as a board member of the Quantum Electronics and Optics Division and 1995-99 as an elected Individual Ordinary Member to the EPS Council.

We met Poulsen at NKT Research, where he is in charge of a staff of 50 employees with core expertise in micro technology and systems, polymer and surface technology, electrical engineering and superconductor technology, and cleaning and environmental technology.

Sheer coincidences

Poulsen thinks that his career is a result of sheer coincidences combined with a strong desire to take up new challenges.

"You cannot plan a career, but you have to be willing to move and try something new. I have never applied for any of the positions I have held, and I don't think I left any of them at an unfortunate time. You should not be blind to the fact that by moving yourself you also create room for new development, and it has been very satisfying to see how the Microelectronics Centre has developed, just as research in quantum optics at the University of Aarhus has driven it much further that I had dared to dream about 10 years ago."

Honesty and openness

Poulsen has always been able to draw attention to himself by sharing his sharp opinions about Danish research and its organisation. Maybe this is also the reason that there are many pointed opinions about him. One characterisation is that he is the reincarnation of the strong natural scientist from the 19th Century, who guides his staff as a feudal warlord surrounded by faithful lieutenants and esquires. Poulsen is amused over the characterisation but cannot recognise himself in it.

"Actually I do have a modern management style where I advocate freedom, honesty and openness. For instance when I work on a research plan together with a student, I see it as my task as a supervisor to ensure that the essential goals in the plan are reached. I have never had a student who did not finish on time and on budget, but my students and group members have always enjoyed full freedom to perform. If a goal is not achieved, then I view it as a joint problem where we analyse what went wrong and what solutions can be found. I cannot accept laziness or waste, but I don't mind that errors are made—if you learn something from them. Actually I often go to the extreme of encouraging errors to be made and I have a certain weakness for civil disobedience, where a students tries out some of his own ideas even if I have predicted that they would not work. Of course some times errors are made that have more serious consequences and in these cases it is the responsibility of the leader to take the full blame instead of passing the problems on to his collaborators.

... I don't mind that errors are made—if you learn something from them. Actually I often go to the extreme of encouraging errors...

In return for this freedom I also find that the supervisor should be generous when it comes to ownership of the ideas that are developed in a research project and unless I myself have really contributed significantly to a publication I do not want to be coauthor of it. There has to be a fundamental honesty, also when it comes to publications, and unfortunately a bad habit has developed at many institutes that the group leader has to have his name on all group publications."

Research builds social relations

"It belongs to the picture of a successful research project that you develop social relations, and in particular as an experimental physicists you develop a close relationship to your students that lasts a lifetime. I am, for example, in contact with all my former students and I myself still listen to advice from my former thesis advisor.

Openness also means that my door always is open for my coworkers, and if they wish to discuss a problem with me, I give priority to this over my other tasks. My management tasks also includes holding individual development talks with my co-workers, where we speak openly about their future. Not with regard to a certain position they should have at a certain time, but which of their personal qualifications we should develop. Therefore I also view it as a success that there was a fast staff turnover of my co-workers in the Ministry of Research, because they moved to promotions. In return for my demands on their work I want my co-workers to have decent conditions, and I have never participated in the university post-doctoral circus where an incredible lack of respect is displayed towards competent people by offering them one short-term employment after another".

When asked to compare his experiences from the universities, the government and industry, Poulsen replies without hesitation, that it does not make any difference where you work:

"I have not met any cultural differences. On the contrary it is everywhere the same engaged and very competent people".

Creativity is killed at conservative universities

The universities and their conditions are still dear to Poulsen's heart.

"Unfortunately in many ways the universities still operate as they have done over the last 400 years, and just because von Humboldt formulated some good ideas about the role of the universities 100 years ago, these ideas are not necessarily optimal today. I find for example that the educational system is far to formal and strict and influenced by an incredible conservatism, which holds both for the distribution of subjects, the curriculum and the teaching methods.

Just as I think it is necessary to make errors in your research, there should also be room for the students to make errors in their studies—instead of immediately being led to the correct solution. In return I demand active participation from the students. They should not have everything served on a silver platter, where each week they are told to read from page A to page B. I have practised this myself when I lectured on non-linear optics at the Danish Technical University, and where I was met by large student protests because I did not follow the lecture book strictly and in addition had the idea that the students should figure out themselves which pages were relevant. The students had not realised that they were no longer in high school but at a university and they were already very conservative in their opinions on how teaching should be given and exams should be held. I learned the latter when I triggered the next wave of protests by introducing some more untraditional forms for examinations.

I am seriously worried that the strict and formal educational system will kill creativity and intuition among students.

I am seriously worried that the strict and formal educational system will kill creativity and intuition among students. I have thus often experienced students who have had a good formal knowledge on, for example, atomic lifetimes, but were not able to participate in a physics discussion on why the 2*s*-state in the hydrogen atom has a long lifetime. And here I do not stress that a student should be immediately able to recite the correct answer, but that he shows an interest in discussing the phenomena and can come up with some suggestions on the cause."

Use the "nerd culture" among physicists to develop new teaching methods

"I don't see any problems in giving up research-based teaching at universities at the undergraduate level. There is no harm done if it takes three years before the students are being introduced directly to research. Some of the best and most inspiring lecturers I have had, were no longer so active in research, but they were still able to bring us to the research front in their lectures. I am not arguing that the physics study should be easier, because you still need good scientific challenges, but today we have so many tools at our disposal, for example computers, that are hardly being used at all in teaching. It should actually be possible to use part of the nerd culture that also exists among physicists to speed up the development of new and effective teaching".

Arrogant and spoiled physicists

You have often asked for a new dialogue between universities and society...

"Yes, and I still don't find it. The universities have locked themselves up in a cage and live in an outdated perception of a researcher as someone who can hide in his office for years, and then expects all news teams in the country to be ready with their TV-cameras the day the researcher finally comes out to tell what he has discovered.

However this is not how the world works anymore. Universities no longer possess a monopoly on producing new knowledge, and therefore it is necessary that they market themselves. Otherwise they will lose the competition for new grants, etc.

You cannot deny that physics is central for the development of society, but unfortunately far too many physicists possess an arrogant and spoiled attitude where they expect that the surrounding world, in deep respect for the importance of physics, will rush forward and overwhelm them with large grants. Instead we see that this arrogance causes the grants to go to subjects other than physics.

A frightening example is the resolution from the EPS in 1999 that "physics is, and must remain, the Leitwissenschaft". I will dismiss the statement as the last primal scream from a bunch of moribund male monkeys, since it sends a totally wrong signal. The same holds for the constant message from physicists that physics is an exact science, since the research front is certainly not exact.

Unfortunately the universities have not been able to or willing to enter the discussion on the changed interaction between society and universities, and therefore I hope that the societies such as the EPS will do this. I also hope that the societies to a larger degree will reflect the production of knowledge in society. The EPS was dominated for a long time by researchers from classical particle physics, but it is my impression that the EPS today makes persistent efforts to make the society more modern and professional and also in direct dialogue with society. It is about time that this happens, and in Denmark I am worried that politicians have totally given up natural science. It is at least not a priority area."

Coming to the end—do you have any good advice to a new student who has to choose an education?

"Make higher demands, select a scientific environment that challenges. However, physicists will always be something exceptional—because if they were not, they would never start studying physics!"

European bureaucracy paralyses innovation: *a Spanish view*

Interview by Carlos Fiolhais and Carlos Pessoa

Europe has a great scientific and technological potential but has to learn a lot from the United States, especially the ability to transform ideas into market products. Pedro Echenique, a Basque physicist is claiming it. He has no doubts about the "supremacy of Europe over the United States if it manages to learn from them". This possibility implies, among other things, the introduction in the universities of "science competitivity", a competitivity which is different from that existing in the market. Professor of Condensed Matter Physics at the University of the Basque Country, in San Sebastian, Spain, he was awarded in 1998 the Prize *Príncipe das Astúrias* in science and technology, the highest science prize in Spain, and is now chairman of the foundation "Donostia International Physics Centre". Echenique was Minister of Education of the Basque government but does not want to return to politics. For two reasons: politics can be a "noble activity, but also very demanding" and, on the other hand, Basque politics "is too complicated".

In your lecture at the University of Coimbra you spoke about "the utility of knowledge", emphasising the importance of basic research. Do you think that pure science is being threatened?

When a country is underdeveloped the perspectives are narrower. Normally, utility is only related to immediate and short term goals and the absence of basic research is inevitable, as a consequence of the concentration of efforts on applied research. It is curious, because that situation results often from ignorance and not from obscure, mean intentions, but it is very detrimental to any country.

A good example, on the other hand, is the United States, which is usually seen as the symbol of mediocre utilitarianism. In fact, they have been quite successful in turning ideas into products. Nevertheless, the triumph of the American system resides in a harmonious confluence between the basic, the applied, the development and the business companies. The managers themselves ask the basic research centres not to deviate from their goals. And they keep asking the government to promote a federal program with a strong component of basic research so that elite universities may undertake their mission.

A situation different from Europe, in every extent...

R – In Europe business dynamics is more bureaucratised. I don't see how the European businessmen are, in any way, similar to the American ones and that gets worst in the South of Europe. Europe has a great technological and scientific potential, but it still has a lot to learn from the Americans, in particular how to turn ideas into market products. That is, Europe may triumph over the United States as long as it learns from them.

Why do you think that happens?

I believe there is an institutional architecture that doesn't promote innovation and the risk inherent in competition, and that reality is stronger in the South of Europe – Italy, Spain, Portugal and even France.

Let us look at the specific case of Spain and Portugal: how do you compare these two situations with the rest of Europe and the United States?

The North American system has several characteristics with a totally different degree of development than that in Spain and Portugal. Two of them, which are fundamental, are the flexibility and variety of the institutions, which imply in their turn a strong competition. It happens that they are always more lucrative than uniformity and equalitarianism. There are many universities in the United States, but the system manages to reconcile the mass education of higher studies and the maintenance of fifty or one hundred elite universities. Of course, these are the ones which keep things moving... Harriman was asked which were the best universities in the world. He answered he didn't know, although he admitted that many were American. "On the other hand", he added, "I know where the worse are: in the United States!" Mass education is only a synonym of bad quality when one wants everything to be the same.

What needs to change in Europe, then?

The answer has to do with the flexibility and heterogeneity of the institutions. And competition is also very important. Europe has an excessively bureaucratised system which, in my opinion, paralyses innovation. I don't know any researcher who isn't scandalised with the bureaucracy from Brussels. There is consensus on this matter and we've come to a situation where various laboratories and research groups who have given up participating in European nets due to the reining bureaucracy. On the contrary, in the United States there is huge competition to obtain funds but the bureaucracy is minimal. Moreover, there are plenty of funds but that doesn't mean they are easy to get. The question is one cannot identify success with quantity, nor failure with a frustrated attempt.

The situation you described is then a basic characteristic in Europe?

Well, in what concerns Europe, one must not generalise because there are many different systems. For instance, the Scandinavian or Anglo-Saxon systems are much different from the Iberian ones. In the South, a system with no incentives – incapable of negotiating individual improvements – will never promote mobility, innovation and risk.

And that cannot be changed by a decree...

Of course not, only through competition! Trying to force everyone to work by decree... we know in what that results. If we want everyone to be good based on a law the result is that everyone will be bad. The only way to resolve this question is one that leads to the conclusion that the quality of our services is lucrative, from the institutional point of view and also from the personal one. If a department chairman is paid according to the products generated by his or her department, he or she will personally take charge of integrating the best researchers in the team and will fight to hire them. Some years ago, "Nature" published a work on the reason why Italy, known for its creativity and innovation, had such non-creative universities. The answer was obvious: if they were financed according to their results, university departments would eventually understand how important it is to have quality professors and fight for them. In other words, it is necessary to cut out uniformity and the bureaucracy that supports it.

Does that mean we should introduce the market competition in the universities?

Competition in science is different from the market competition; it is ruled by other parameters. Scientific parameters, parameters which measure quality in science, are distinct from market criteria – these can be short term criteria, for instance.

Tell us more about your scientific career. How and when began your interest in Physics?

I don't believe in vocations pre-established since the cradle. Personally, I enjoy many other things besides physics, like literature, history, a lot of things! There are subjects for which I don't have great sensibility, like music or painting, but I like everything that is well done, done with passion. Of course, I always liked everything which was quantitative, Mathematics, Physics. The first notions of Quantum Physics caused a big impact in me, but I always found the teaching of Classical Physics very dull. It's a miracle how vocations survive with that kind of probation...

Why did you choose Surface Physics?

I have been working in Condensed Matter Physics and not only on Surface Physics. One of the major themes of my work concerns interaction of charges and radiation with matter – for example, how a proton which enters a material is stopped, how the electrons in a solid are excited when interacting with external charges. This area is very interesting for its diversity, since the interaction of particles with matter combines modern techniques of Solid State Physics with ideas and intuitions of Atomic Physics, etc. It also presents a unique characteristic: it operates by successive approximations of finding more adequate ways of solving a complex problem. That is fundamental to study the complexity of the interactions which rule condensed matter.

In what problems are you working presently?

I'm working in distinct areas, even though related, of Condensed Matter and Radiation Physics. More precisely, I work in the problem of dynamic response to external disturbances in solids and surfaces. I am also studying the average lifetime of stimulated electrons above the Fermi level, a subject which is essential to understand chemical reactions in surfaces, part of a new domain known as Femtosecond Chemistry.

The problem of energy transfer from slow and fast ions to condensed matter also interests me. It is a classical field in Physics since the pioneer works of Bohr and Bethe, but is very actual because of the complex challenges it presents in the theoretical domain and also for its practical applications in the medical and microelectronic industries, only to mention two examples. Another problem that interests me belongs to the field of electronic microscopy, more precisely the transmission that allows the study of the interaction of relativistic electron beams with solids and supplies information about surfaces and their excitation modes in the external and internal surfaces of the materials. Our research group works very hard on this spectroscopy that provides a spatial resolution at one nanometer or even one angstrom scale.

After being awarded the "Prince of Asturias" Prize, the most prestigious Spanish prize for science and technology, you created an International Centre for Physics, in San Sebastian – the Donostia International Physics Centre. What are its goals?

One of its main missions is to internationalise our research. Science is, above all, creativity. Therefore, it cannot be taught as a series of rules or as a prescriptive method, the self-proclaimed scientific method. Things don't work that way, because there are diffuse components of irrational nature that cannot be decoded. So, the best way of learning how to do good science is to imitate the best ones... It's the only way and can only be practiced in two ways: going to the high quality research centres, or bring good researcher to join us. We do both. Summarising, what we want is to create a good working environment without rigid bureaucratic rules. We resort to the good things we learn in the best research places. We promote three annual international meetings in San Sebastian, where team directors discuss hot topics. We also develop a program, supported by the regional government of the province of Guipuzcoa, aiming at researchers who have done post-doctorate works, enabling them to research whatever they like for five years. They have total freedom to explore any links, whether it is in university or in industry. Another axis of our work has to do with the public understanding of science. Last year, for example, we organised a multidisciplinary symposium on the scientific legacy of the 20th century.

How do you articulate all this activity with the university?

All our activities are intrinsically connected to the University of the Basque Country, which is a member of the Foundation that manages the International Centre for Physics. All the activities are done in collaboration with the university's Department of Materials, where the researchers are. The articulation is total, that is, functional and not bureaucratic. Behind the Foundation there is what I use to call an example of institutional cooperation with a strategic view of the future. The university provides the maintenance of the Foundation whose budget will be, in the next year, one million dollars. The larger financing, however, proceeds from the regional government of the province of Guipuzcoa and from the hydroelectric business company Iberduero.

You were Minister of Education in the Basque government for four years. How do you see the articulation between science and politics?

It is curious that that question is recurrently asked to scientists, but not to lawyers or economists... It seems to contain the misconception that politics is more suitable to lawyers and economists than to scientists. That is a serious mistake, because if politics is left in the sole hands of lawyers it will, no doubt, be conducted under strict rules. That is one of the "sins" of Europe: over-regulated societies. That explains, for instance, why any idea of change manifested in a Spanish university stumbles upon a juridicial framework. It's impossible to work under these constraints! There should be people from all areas in politics. This is not a scientific activity in the sense the scientists are better prepared for it than other people, but it is an activity in which, as in others, it is important to recognise and admit an error when it occurs.

But, is it possible to do politics and science at the same time?

No, it's impossible. There is much that is noble in Politics as an activity, but also it is very demanding for it requires a lot of responsibility. The problem is not so much the lack of time, but rather the absence of serenity, reflection and peace necessary to think about science.

Do you foresee returning to politics?

No. Basque politics is too complicated!

Physics in Estonia—Institute of Physics at Tartu

Henn Kââmbre, Kristjan Haller

Introduction by Maurice Jacob.

I still remember very well the visit of the president of the physical society of Estonia to the EPS Council in Uppsala, in 1990. He was seeking admission of his newly created society to the EPS. Estonia was actually the first of the many new countries which resulted from the dislocation of the Soviet Union and of Yugoslavia, to make such a move. During my two years of presidency (1991-93), I could speed up things through many contacts and discussions and, already in 1992, at the Council meeting in Athens, the Estonian physical society, together with those of Lithuania and of Albania were welcomed as new member societies. Those of Armenia, Bellarus, Croatia and Slovenia, were soon to follow. I had since the pleasure to visit Estonia in 1995 and in 2001.

We can but admire the vigour with which physicists in these new countries decided to organise themselves and to participate in our European endeavour. Nevertheless the fragmentation of large political entities have left some important and thriving physics institutes within small countries which can hardly support by themselves such research centres. Yet they deserve to survive and prosper. This can only occur through their developing strong international ties and collaborations. Their potential and present problems should be better known within Europe and Europhysics News is an efficient vector for that purpose. We are glad to start such a survey with an article on the Physics Institute of Tartu, Estonia, which has been recognised as a centre of excellence by the European Union.

Historical background

Estonia, with its only some 1,4 million inhabitants and 45000 km2 area, is the smallest among the triplet of Baltic republics. Having been for seven centuries under foreign rulers, it won its independence in 1918, to lose it again already in 1940 as a victim of the Ribbentrop-Molotov deal. It was re-established as an independent country in 1991 as a result of the 'singing revolution'.

Now it is praised as one of the most successful among the newly independent countries and looks forward to joining soon the EU and NATO. Estonia has been also one of the most successful countries among Eastern and Central European ones in the 'fight' for EU research money, despite only about 0.7% of GNP being spent for research purposes, mainly from the state budget.

Exact sciences, physics among them, have some centuries-long traditions in Estonia. Sven Dimberg lectured on Newton's mechanics at the Academia Gustaviana (opened in 1632 in Tartu) already some years after the appearance of the Principia, being one of its first popularisers in the world. Emil Lenz, whose name is known to everyone quite from the school years, was a son of the magistrate secretary of Tartu. At the Tartu University he started his physics studies, at the first time as a hobby of a theology student. World-known physico-chemists, a nobelist Wilhelm Ostwald and Gustav Tamman have lectured here, and the thermo-compensated seismographs of Estonian physics professor Johan Vilip were popular for decades among seismologists all over the world.

The contemporary state

Physics is one of the most developed sciences in contemporary Estonia. Its rapid development started in the middle of the last century. Seemingly, several circumstances stimulated then the physics boom. The launching of sputniks induced the popularity of hard sciences all over the world. Further, here in Estonia, the youth, annoyed by the over-ideologisation of humanities, rushed into physics department as one of the most apolitical ones. And Soviet officials supported to a certain extent physics and exact sciences in general as a basis for military and industrial power.

Physics and related topics are developed in several research institutions and universities over Estonia, but most productively in the Institute of Physics of the University of Tartu.

In 1946 its first predecessor, the Institute of Physics, Mathematics and Mechanics of the Academy of Sciences was established. So the Institute can look back to a half-century long history. Concentration of scientific research in specialised research institutions was the Soviet system of science organisation. Basic research was mainly associated under the umbrella of the Academy of Sciences as a kind of science ministry. The Academies of the Soviet republics, accordingly, had to copy this role. The shortcoming of this system is the somewhat loose connection of science with the educational system (though the students were, as a rule, participating in the research work of the academic institutes), but, on the other hand, it facilitates more devoted research work of the scientists and independence of the science organisation.

After several reorganisations, the Institute was incorporated into the University of Tartu in 1997, as an autonomous research establishment in the framework of the university. In 2000 the Institute has received from the EC the status of a Centre of Excellence and in the following year it has been included into the list of the first six Estonian own Centres of Excellence.

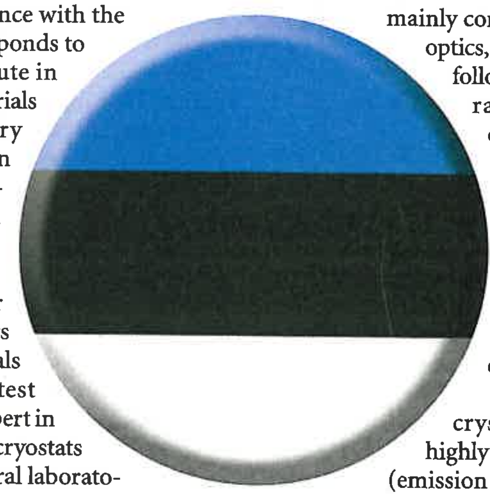
At the moment there are 148 persons in the permanent staff of the Institute, including 76 scientists with a scientific degree. In comparison with the great scientific institutions, this is, of course, a rather small research establishment. However, its scientific productivity is one of the highest of the nation. Annually, some 120 papers are published in peer refereed journals, abstracted in Current Contents and/or Physics Abstracts. Approximately the same number of reports is made at international conferences. The importance of the Institute in maintaining the science level in the country, contributing to its national culture is quite high. Most of the members of the scientific staff are also engaged in teaching at the University (and have been throughout the history of the Institute).

At two international evaluations (1992, 2001) the Institute and its research activities have received the highest assessments and stated to be '...a national asset'.

To a great extent, the success is bound to the tight international links. The Institute has scientific collaboration connections with the universities and institutions in 22 countries. Among the most involved partners are in Sweden, Germany, Finland, France, and USA. Having restricted funds for modernisation of our equipment, it is a good idea, almost a sole possibility, to carry out a substantial deal of experimental work at foreign laboratories, in collaboration with the local scientists there. Naturally, this mobility enhances also the exchange of ideas, skills and know-how.

The activity areas

The overwhelming majority of the Institute's activities are in the field of materials science and technology, an area fixed in 2001 by the Estonian Parliament as one of the 3 priority R&D areas in Estonia. This field is in the best accordance with the national and European needs and corresponds to the long-time experience of the Institute in solid-state physics. In particular, the materials for thin film gas sensors, optical memory devices, solid-state lasers, and radiation detectors (including materials for bio-equivalent fast neutron personal dosimeters) are being elaborated. Atomic layer deposition and laser ablation technology have been successfully adapted for preparation of thin films for gas detectors and other purposes. A part of the materials science is the advancement of proper test devices. Here, the Institute has been an expert in the design and manufacturing of helium cryostats for investigating different materials. Several laboratories worldwide use our versatile module cryostats. During the last few years the designing and manufacturing of SPMs, scanning probe microscopes (tunnelling as well as atomic force) has got into full swing at the Institute, in collaboration with Swedish and Latvian scientists. New modifications of these devices have been elaborated, including ones usable at low temperatures as well as combinations of SPM and a transmission electron microscope.



The other basic areas of R&D-activities of the Institute are: Basic theory of the structure of matter, embracing the theory of elementary particles and fields as well as the theory of molecules and solids, in particular, ferroelectrics and high temperature superconductors.

Laser physics and laser optical technologies

The interest in laser physics and even laser manufacturing has arisen already several decades ago when the Institute had no finances to purchase commercial laser equipment and endeavoured to replace it with homemade pieces. In collaboration with the Special Design Bureau (functioning then) of the Estonian Academy of Sciences a number of excimer lasers and dye lasers was designed and manufactured. On this basis in the re-established Estonian Republic several laser-producing companies came into being. Two of them (Estla and Neweks) are still actively functioning and exporting their production mainly to Germany, Great Britain, Japan, Finland and USA. Neweks is one of the main excimer laser producers in the world, producing also the most compact lasers of this kind, e.g. for medical purposes. Estla, in collaboration with the Institute's scientists, has developed a copper vapour laser for healing of dermatological diseases. The laser has proved to be very effective in the course of clinical tests at Tartu and Helsinki.

Environmental science

Here, the focus is on the environmental radioactivity. The issue is rather acute in Estonia, where huge radioactive waste deposits remain in Northern Estonia (Sillamae) from the times when the raw material for the Soviet atomic bombs was supplied there.

Biophysics

Research is concentrated upon the elucidation of physical microprocesses (solar energy transformation and energy transfer acts) in photosynthesising bacteria.

From the research highlights, first, should be mentioned the resonance mechanism of the mu-meson-mediated nuclear fusion, now generally known as the Vesman mechanism, after its discoverer Elmar Vesman from the Institute. Other highlights are mainly connected with laser spectroscopy and laser optics, such as spectral hole burning and the issues following from it, such as time-domain holography, the principles of the high density optical memory and highly selective optical filters. Spectral hole burning, first realised in Tartu, is now a topic of hundreds of publications and even specialised conferences. In laser optics, the virtually non-diverging light beams—the Bessel-X-beams, and other non-traditional laser beams were generated and studied here.

The discoveries of hot luminescence of crystals and molecules (luminescence from highly vibrational excited states), photon cutting (emission of several photons in response to a single absorbed photon), and transformation of electron excitations in a crystal into lattice defects should be also mentioned as some discoveries first found in the Institute of Physics in Tartu. The list is far from being complete.

Development perspectives

A large part of the research carried out in the Institute of Physics belongs to the basic science. Unfortunately less and less funds are being utilised for fundamental research in many countries, including Estonia. Reorientation towards more active applied research and development activities is under way here but corresponding resources at our disposal are very limited. On the other hand, education and 'brain resources' are a little more developed than national high-tech industry. This circumstance reduces the prospect for a quick transformation towards technological projects. The wages in a scientific institution in contemporary Estonia (some 500 - 600 EUR per month on average) are also too low (drastically in comparison with the private sector) to attract the most gifted youth, especially from abroad, but also from Estonia. Though the recent EC Centre of Excellence grant significantly improved the mobility conditions of scientists (e.g. 31 foreign researchers worked in our Institute during the year 2001), the problem is far from a proper solution.

There are two principal ways to improve the situation described and not lose the brain and research potentials of the country. The first would be to achieve a high-tech industry transfer to the country. This raises and widens the demand for R&D. The second would be the 'purchase' of local research groups or full institutions by larger research or industrial institutions of developed countries, e.g. when great scientific institutions are wholly given over to foreign administration and financing. Some similar steps have already been planned or taken in Estonia as well. From its own side, the Institute is applying every possible effort to facilitate nationally the development of high-tech industry, first of all in undertaking research projects with local application perspectives. Close collaboration with other research centres, SME-s, spin-off companies of the Institute and with the Tartu Science Park, also favour these endeavours.

To approach the needs of everyday life is now the great challenge for the Institute.

Hannes Alfén Prize to Marshall N. Rosenbluth

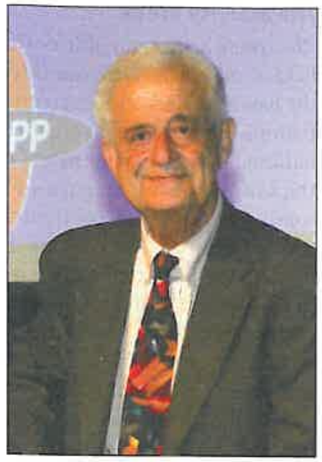
Friedrich Wagner
Max-Planck-Institut für Plasmaphysik, Garching, Germany

The 2002 Hannes Alfvén Prize of the European Physical Society for outstanding contributions to plasma physics has been awarded to Marshall N. Rosenbluth "For his seminal theoretical contributions since the earliest days of fusion research in virtually all aspects of fusion plasma sciences which now form the basis of modern plasma physics. The work of Marshall N. Rosenbluth has enriched the understanding and has accelerated progress toward the realisation of fusion energy."

Marshall Rosenbluth was born on February 5, 1927 in Albany, New York. He was educated at Harvard University (B.S., 1946) and the University of Chicago (Ph.D., 1949). He has subsequently held professorships at the University of California, San Diego, the Institute for Advanced Study at Princeton, and the University of Texas, Austin (Fondren Chair). He has also had a long association with General Atomics.

Rosenbluth has won numerous awards, most notably the E.O. Lawrence Memorial Award, the Albert Einstein Award, the James Clerk Maxwell Prize in Plasma Physics, the Enrico Fermi Award from the U.S. Department of Energy, the National Medal of Science, and the American Physical Society Nicholson Medal for Humanitarian Service. He is a member of the National Academy of Sciences and of the American Academy of Arts and Sciences.

Marshall Rosenbluth has made seminal contributions to particle and nuclear theory, computational and mathematical physics and has virtually defined the fields of theoretical plasma and fusion physics. To nuclear theory he contributed with the analysis of the scattering of relativistic electrons by nuclei and provided the theoretical background on the structure and charge distribution within nuclei.



His many theoretical contributions have influenced nearly every aspect of plasma physics, particularly the science of both magnetic and inertial fusion plasmas. His groundbreaking works on resistive instabilities, tokamak and mirror microinstabilities, stochasticity, energy principles, free electron laser dynamics, energetic and alpha particle-driven modes and transport theory are classic works, studied and admired by all plasma physicists.

Rosenbluth has also served as a key advisor to the Department of Energy for magnetic and inertial confinement fusion and for aspects of national defense and disarmament planning. He has served as a member of JASON for over thirty-five years and he was an early, strong proponent of collaboration with the fusion scientists of the former Soviet Union.

Throughout his long career Rosenbluth has combined deep physical insight and great calculational strength with an enduring dedication to the vision of fusion energy, all making him the stuff of legend to several generations of fusion students and researchers. He is known to and admired by all for his dedication to science, intellectual integrity, fairness, accessibility and his keen wit and sense of humor. He has trained and mentored an entire school of postdocs in theoretical plasma physics and many of them are now leading scientists in the program. He has tirelessly worked to enhance international cooperation in science and in general.

noticeboard

Agilent Technologies Prize Winners 2002

The 2002 Agilent Technologies Europhysics Prize is awarded to

Bernard BARBARA (CNRS, Grenoble, FRANCE)
Jonathan FRIEDMAN (Amhearst College, Ma, USA)
Dante GATTESCHI (University of Florence, ITALY)
Roberta SESSOLI (University of Fierenze, ITALY)
Wolfgand WERNSDORFER (CNRS, Grenoble, FRANCE)

For developing the field of quantum dynamics of nano magnets, including the discovery of quantum tunnelling and interference in dynamics of magnetisation.

Nuclear Physics Board

The EPS would like to welcome the three new members of the Nuclear Physics
Division Board: O. Scholten (Groningen), Nguyen Van Giai (Orsay) and Z. Sujkowski (Swierk, Poland). We would also like to take this opportunity to thank the three outgoing members for their work over the past six years
G. Rohozinski (Prague), B. Vignon (Grenoble), and A. van der Woude (Groningen).

EPS Public Understanding of Physics Prize 2002

The 2002 EPS Public Understanding of Physics Prize has been awarded to R. Carreras (CERN) for his outstanding contributions to the popularisation of Physics.

Lise Meitner Prize 2002

The 2002 Lise Meitner Prize sponsored by Canberra Eurisys is awarded to

Prof. James Phillip Elliott, University of Sussex, (UK) and Prof. Francesco Iachello, University of Yale (USA)

For their innovative applications of group theoretical methods to the
understanding of atomic nuclei

INTAS' writing competition for young scientists

INTAS (international association promoting scientific co-operation between its members states and its NIS partners) announces its second writing competition for NIS young scientists, who were awarded an INTAS grant. Prizes will reward the best three articles.

Young scientists who were awarded a grant, either in the INTAS fellowship program or as an individual grant in an INTAS project, can submit an article presenting their research results to a lay audience, such as industry, policy-makers, non-scientists, etc. If you, an INTAS young scientist, have finished a project since January 2000, send us an article of not more than 1000 words by 13 September 2002.

We are looking for the story behind the research! Simple words, a hint of humour and journalistic style should be your tools to highlight the relevance of your research and its applications (direct or indirect) to national and/or international communities. As accessible writing is the essence of the competition, a panel of predominantly scientific copy writers will judge the eligible articles, focusing on the young scientist's ability to explain science in simple terms.

INTAS will announce the winners of the competition in November 2002. The author of the best article will receive 800€. There is also a prize of 400€ for the runner-up, and one of 200€ for the third place competitor. All winning texts will be featured on the INTAS web site.

For additional information and guidelines on this competition, please contact Joelle Lepot at lepot@intas.be, or Aoife Leydon at leydon@intas.be, or by fax on +32-2-549 01 56.

For more information about INTAS in general, please consult the web site www.intas.be or contact the Public Relations department by e-mail: intas@intas.be

EPS Gero Thomas Memorial Medal 2002

The 2002 Gero Thomas Memorial Medal has been awarded to E. W. A. Lingeman for his many important and valuable contributions to the EPS.

Victor Weisskopf

19th September 1908 – 21st January 2002

Maurice Jacob, CERN, Switzerland

With the death of Victor (Viki) Weisskopf earlier this year the world of physics lost one of its most prominent citizens. He was renowned in that world and beyond, not only for his seminal contributions to the subject but for his leadership of important institutions on both sides of the Atlantic and for his unflagging efforts to remind all of us of the great dangers of the nuclear arms race.

Victor Frederik Weisskopf was born in 1908, the scion of an intellectual Viennese family. His father was a lawyer. He was raised in Vienna. As a child he learned to play the piano to a standard that allowed him to contemplate being a professional musician. Fortunately for the world of physics he chose science. After studying physics at the University of Vienna he moved to the University of Göttingen where he received his PhD in 1931. From 1932-33 he was a research assistant with Niels Bohr in Copenhagen before becoming Pauli's assistant at ETH in Zürich from 1934 to 1936. In his own words he was "living through the golden age of physics". A surprising comment given that he was in contact with Heisenberg and Schrödinger as well as Bohr. With Bohr he described the group spirit as "... approaching the deepest riddles of nature with a spirit of attack, a freedom from conventional bounds and a spirit of joy which can hardly be described." With Pauli he could say "It was absolutely marvellous working for Pauli." Apparently you could ask him anything since "There was no worry that he would think a particular question was stupid, since he thought all questions were stupid."

No wonder then that it brought out the best in Weisskopf. He made seminal contributions to nuclear physics and the early developments of quantum field theory and later to particle physics. Amongst his early pieces of work was the Wigner-Weisskopf approach to line widths with which we are all familiar. His direct contributions to physics were important but at an early stage he was noted for his ability to get to the heart of the matter; to see behind the mathematical formulation of a problem and re-state it clearly in a way others could understand. He was a genius at understanding a phenomenon and outlining its essence in terms of orders-of-magnitude. Hence the "Weisskopf units" which bear his name.

Their aim was to warn society of the dire consequences of nuclear war and to advocate the peaceful applications of nuclear physics.

Flight to the US

By the mid-thirties Weisskopf was already well known. However the gathering storm clouds in Europe forced him, like many others of Jewish origin, to emigrate. So just before the Anschluss he left to become an assistant professor at the University of Rochester. In 1943 he became a US citizen, joined the Manhattan Project as a group leader in Hans Bethe's Theory Division and was engaged on the theoretical design of the atomic bomb. He made important contributions to the success of the project but it left a sour taste. In 1944 he became a founder member of the Federation of Atomic Scientists. Their aim was to warn society of the dire consequences of nuclear war and to advocate the peaceful applications of nuclear physics. Later he was a member of the Emergency Committee of Scientists, which had the same goals under Einstein's chairmanship. For the rest of his life this was an unfailing theme and he used his various offices and his prestige to put forward the message.

After Los Alamos and the war years he accepted a chair at MIT and took up his theoretical work again. It was in this period that he and his student J B French made the first correct calculation of the Lamb shift. This involved a deep insight into how the various divergences in electrodynamics cancel each other out. He also developed the cloudy crystal ball model of nuclear reactions with Feshbach and Porter and he wrote his famous and influential text book "Theoretical Nuclear Physics" with John Blatt.

The CERN years

While on leave from MIT he became Director General of CERN, a position he held from 1961 to 1965, a crucial time for the organisation. He was the first US citizen to hold the position; a considerable honour given that the US was not a member. Under his leadership he elevated CERN from an experiment in international collaboration to its present status. He shaped its future in a way which allowed Louis Leprince-Ringuet to say of him that "the spirit of CERN is his creation." When he left CERN in 1965 he confidently predicted that "the golden age of CERN is ahead of us". He was a very difficult act to follow.

On returning to MIT he became chairman of the physics department in 1967 and from 1967-73 he served as chairman of the high-energy physics advisory panel at the US Atomic Energy Commission. Even after retirement his leadership in science was still important in several countries and he continued to wield his influence until advancing age made it impossible.

Weisskopf received many honours including the Wolf prize, the Planck medal, the Oppenheimer medal and the Fermi award. He was a member of the US National Academy of Sciences and of many European academies, he served as President of the American Physical Society from 1959-61 and as President of the Academy of Arts and Science from 1976-79.

He met his first wife, Ellen Tvede, in his Copenhagen years and they married in 1934. They had two children; a daughter Karen who now works in the Boston school system and a son Thomas who is professor of economics at the University of Michigan. Ellen died in 1989 and in 1991 he married Duscha Schmid, former Director of the Jackson Homestead Museum in Newton, Massachusetts. She shared the last decade of his very full life and survives him.

Three themes stand out in Weisskopf's life; music, quantum mechanics and his strong sense of duty to his fellow citizens. At his retirement party he played the piano in a Beethoven trio and conducted the institute's orchestra in one of Bach's Brandenburg Concertos. It is not surprising then that he once said "When life is hard there are two things which make it worth living—Mozart and quantum mechanics". His leadership in scientific institutions on both sides of the Atlantic and his devoted opposition to the nuclear arms race amply attest to his devotion to his fellow citizens.

Contact **Susan Mackie** • EDP Sciences • 250, rue Saint Jacques • F-75005 Paris • France
Phone +33 (0)1 55 42 50 51 • fax +33 (0)1 46 33 21 06 • e-mail mackie@edpsciences.org

ISTITUTO NAZIONALE PER LA FISICA DELLA MATERIA

Marie Curie Fellowships for doctoral students in Materials and Plasma Science

are available at Università degli Studi di **Milano Bicocca** and Università degli Studi di **Roma Tor Vergata** in the field of **Materials and Plasma Science** in the following topics:

- growth and/or characterisation of materials and systems for micro- and opto- electronics,
- neutron spectroscopy,
- spectroscopy of low and high temperature plasmas,
- surface physics.

Details on projects and application can be found at http://www.infm.it/lavoro/trainingsite.htm or by e-mail reclutamento@infm.it

BESSY

The Berlin research institute BESSY runs an electron storage ring based light source dedicated to the vacuum ultra-violet and soft X-ray region serving domestic and international research groups.

The high-brilliance synchrotron radiation source BESSY II has shown its extra-ordinary capabilities. To guarantee the ultimate level of quality while further development takes place is the challenge now. In addition BESSY plans to build a free electron laser (FEL) to provide a next generation light source.

We are looking for:

PhD Physicists (m/f)

Scope of the open positions is quality-assurance of the site by identification, characterization and correction of smallest perturbation effects. Fault-tolerant operation sequences and expert knowledge have to be implemented in a software context that is ready to support test and commissioning of the FEL.

Candidates should be knowledgeable in generation of complex software packages in UNIX environments. Fundamentals in accelerator physics or experiences in accelerator operation are appreciated.

Work contracts conform to the framework of the Bundes-Angestelltentarifvertrag.

Please send your application to

Berliner Elektronenspeicherring-Gesellschaft
für Synchrotronstrahlung m.b.H. (BESSY)
- Personalverwaltung -
Albert-Einstein-Str. 15, 12489 Berlin-Adlershof

LIP

Laboratory for Instrumentation and Experimental Particle Physics

Av. Elias Garcia 14 – 1°, 1000-149, Portugal

The Lisbon branch of LIP anticipates the opening of a three year research position for experimental high energy physicists. Only applicants with a solid CV and, at least, two years experience after PhD will be considered. This position can be converted in a staff position at the end of the three year contract.

The present activities of LIP Lisbon group cover both the participation in experiments at CERN (NA50, DELPHI, ATLAS and CMS) and the preparation of experiments to be installed in the International Space Station (AMS and EUSO).

Further details can be found in http://www.lip.pt.

Questions and declaration of interest should be addressed to Natalia@lip.pt

TU VIENNA

Announcement of an open permanent position at the Atominstitut of the Austrian Universities,
Faculty of Science and Informatics at the Vienna University of Technology.

Tenured Full Professorship in Atomic and Nuclear Physics

The applicant is expected to have outstanding academic credentials in the fields of theoretical and experimental Atomic and Nuclear Physics. Special consideration will be given to the applicant's ability and willingness to establish collaborations with institutions working in related fields of research in the Vienna region.

The applicant must meet the following requirements:

- an Austrian or equivalent foreign terminal academic degree in the field under consideration,
- an outstanding academic track record in research and teaching,
- pedagogic and didactic skills,
- leadership abilities,
- international work experience in the field of research.

Application deadline: September 30,2002

The Vienna University of Technology is committed to increase female employment in leading scientist positions. Qualified female applicants are expressly encouraged to apply and will be given preference when equally qualified.

Applications including a detailed curriculum vitae,a list of publications,and copies of the fivemost outstanding publications of the applicant should be sent to the Dekan at der Fakultät für TNI, Getreidemarkt 9,1060 Vienna, Austria.

LIMANS III: European Cluster of Large Scale Laser Installations

CUSBO
Centre for Ultrafast Science and Biomedical Optics
Milano, Italy

LCVU
Laser Centre Vrije Universiteit
Amsterdam, Netherlands

LENS
European Laboratory for Non-Linear Spectroscopy
Firenze, Italy

LIF-LOA
Laboratoire d'Optique Appliquée
École Polytechnique
Palaiseau, France

LLC
Lund Laser Centre
Lund University
Lund, Sweden

MBI
Max-Born-Institut
for Nonlinear Optics and Short Pulse Spectroscopy
Berlin, Germany

ULF-FORTH
Ultraviolet Laser Facility
Foundation for Research and Technology - Hellas
Iraklion, Crete, Greece

Call for proposals

The above institutions are funded under the current IHP Programme of the European Union to provide access to researchers or research teams of Member States and Associated States. Within the cluster they offer state-of-the-art scientific laser equipment and research environments with a wide range of research opportunities, allowing for today's most advanced light-matter interaction experiments in broad regimes of power, wavelengths, or pulse durations. Access is provided free of charge; travel and living expenses are covered by the host institution.

Interested researchers are invited to contact the LIMANS III website at **http://limans3.mbi-berlin.de**, from where they find all relevant information about the participating facilities and local contact points. Access is granted on the basis of proposals, which will be reviewed by an external panel of referees. Details about the submission procedure may be found on the LIMANS III website. Applicants are encouraged to contact any of the facilities directly to obtain additional information and assistance in preparing a proposal. Proposals are accepted at any time and from any eligible researcher or research team.