## PLENARY SESSIONS

# Lessons To Be Learnt

As is often the case at General Conferences, we were treated to a series of plenary talks displaying a remarkable breadth and depth of understanding but given with the clarity and authority that comes of mastering a specialist field. The audience was never bored, often rivetted and sometimes maybe spellbound thanks to genuine efforts by the speakers to cater to a general audience without trying to gloss over essential details. And most of the time there was a simple lesson to be learnt that should serve us well in working to profit from a cultured pragmatism.

*H. de Waard (left), the Chairman of the EPS-8 International Programme Committee, and H.A. Bethe (right) relaxing.*

### Keep Classical Physics

The opening plenary talk by **K. Knop** (PSI, Zürich) served as a timely reminder of the risks attached to ignoring classical fields of physics. The application of submicron lithographic techniques, developed for integrated circuits, to produce micro-

*K. Knop demonstrates his diffractive colour transparencies.*

relief structures, combined with accurate numerical solutions to Maxwell's equations had opened up a wealth of possibilities in the area of diffractive optics.

Huygens' principle is often not sufficient for a precise and detailed understanding of diffraction phenomena. It is based on the assumption that a wavefront after passing through the diffractive structure may be obtained from the original wave amplitude simply by multiplying by the complex transmission function. Meaningful results can be obtained if the spacing of a diffraction grating is very much larger than the wavelength of incident light, but this is often not the case.

A captivating demonstration of a modern diffractive structure was provided by the speaker showing that an colourless, apparently featureless, transparency produced beautiful coloured images by projection: three overlapping patterned gratings provided the three basic subtractive colours.

### Physics Exports

The talk by **G. Toulouse** (ENS, Paris) on the contribution of statistical physics to neural network theory illustrated that classical concepts can be exported to the very heart of modern computing technology. Indeed, solutions to certain problems in network theory had recently become the basis of a new industry.

The speaker traced the many successes since a 1982 breakthrough by Hopfield in grappling with the problem of why a computer is not able to recognize a human face in a predicted time 100 times faster than for a pigeon. The breakthrough was an exact solution for a neural network with complete feedback (each neuron is coupled to every other neuron). Paradoxically, the advance was also a step backwards because it assumed the biologically unsatisfactory feature that coupling between neurons was always the same in both directions.

Gardner in 1985 proposed dealing with the problem from the reverse side in an unusual departure from conventional statistical physics. Given a set of patterns to be stored, one finds the couplings that stabilize them (see *Europhysics News* **21** (1990) 108). The advantage is that absolute results are obtained for the learning capacity independent of a particular learning rule (*i.e.* thermodynamic-like properties). With the new formulation it was in fact unnecessary to assume symmetric

*L. Pietronero arguing that the Universe is fractal.*

couplings (synapses) so bounds and limitations for a other network structures could be worked out.

However, statistical physicists in seeking to understand intelligence are more adventurous. Not content with limits, they are now outlining the science of complex adaptive systems. Perhaps we shall hear about them at EPS-9?

### Physics Imports

Physics imports as well as exports its tools! and fractal geometry is an excellent example. **L. Pietronero** (University of Rome ''La Sapienze'') demonstrated how it can be used to characterize structures that are intrinsically irregular on the largest imaginable dimension, namely the distribution of galaxies in the Universe with its ''clusters of galaxies, large voids and superclusters, and walls of galaxies''. His controversial personal view was that this distribution is fractal up to observational limits; and that a fractal analysis predicts different results to the standard approach which assumes homogeneity.

A serious problem remains however. Why does nature apparently allow fractal structures to form? Concepts based on physical growth processes have not got anywhere as they have a major stumbling block: one is dealing with irreversible processes with long-range correlations. An alternative theoretical approach has been proposed by the speaker based on viewing the fractal structure as an attractor with a ''fixed scale transformation'' where the dynamic evolution of the structure always occurs at the same scale. The approach seems to work, at least for the problems tested so far.

### Applications Before Understanding

**K.A. Müller** (IBM, Zürich), in his remarkably succinct yet comprehensive summary of developments in high temperature superconductivity, gave us another insight: applications may come before understanding. The two or three quite promising commercial developments may well emerge before the underlying mechanisms for superconductivity in the layered

*K.A. Müller, the 1988 Nobel laureate, discussing the latest in high $T_c$'s.*

cuprates are understood. In "keeping their secrets", the so-called block layers between one or more $CuO_2$ layers either accept or donate electrons (as in the case of intercalated graphites). Properties point to mechanisms, perhaps mixed, involving electron-phonon coupling normal to the $CuO_2$ planes, and an in-plane analogy to a heavy fermion system (see *Europhysics News* **20** (1989) 159).

**Keep The Computer Running**

The theory developed by **H.A. Bethe** (Cornell University, USA) of how one of the two types of supernovae explodes derived largely from a serrependitious oversight. In a Type 2 supernova explosion, the core of an exploding massive star weighing about 1.3 solar masses collapses under gravity to a radius of some 20 km. A rebound or "prompt" shock forms when the core exceeds nuclear density. But according to most computations, this shock cannot penetrate all the way through the core.

J.R. Wilson inadvertently left his computer simulation running overnight and in the morning found that the shock had revived. It turned out that this was due to the adsorption of neutrinos and the outcome was the formation of a huge, empty bubble in which the pressure is provided by EM radiation and electron pairs.

The problem, however, is that the model has some unsatisfactory features. 1) The neutrino red shift no longer worked and one had to introduce "salt fingers" to increase the flux of neutrinos from inside. 2) The predicted explosion energy was three times too small. 3) The expanding bubble should experience a Rayleigh-Taylor instability. Professor Bethe showed how these problems could be resolved by the presence of convection cells that transfer energy from the neutrino sphere to the shock front.

**Imagine The Unimaginable**

*Part 1: Carnivorous pulsars*

Discovered only eight years ago, millisecond pulsars as their name suggests, emit a pulse of electromagnetic radiation every millisecond or so (equivalent to E flat). With a frequency known to atoseconds, they are a test bed for relativistic phenomena (like clocks running a few milliseconds faster in summer than in winter and microseconds faster during a full moon) owing to gravitational effects. **E. van den Heuvel** (University of Amsterdam) led the audience through a remarkably clear description of how these astronomical objects weighing 8 solar mass, with a density of $10^{24}$ g/cm$^3$ (equivalent to the world's population in a raindrop), came to be understood.

Radio pulsars were discovered in 1967 and a pulsar with higher frequency (1/30 sec) in 1968. The latter could only have been a rapidly spinning neutron star with a strong magnetic field. About 520 pulsars have since been identified and there are probably $5 \times 10^5$ still living in our Galaxy. They die after $10^7$ years when the electric field generated by the rotating magnetic field is too weak for emission owing to a decaying magnetization.

*E. van den Heuvel explaining heavenly E flat.*

This was the elegant picture until eight years ago before the discovery of the millisecond pulsar. A total of 16 have now been found, mostly in globular clusters but with a high percentage (40% as compared to only 2% for normal pulsars) in double clusters of stars. They invariably have relatively low magnetic field strengths and a $10^6$ times slower spin-down rate.

So what are millisecond pulsars ? The idea of "recycling" was introduced at first, based on the observation that they often arose in binary stars. It was envisaged that matter fell into the neutron star from the companion star. However, this results in "spin-up" which can only continue until the star reaches the speed at which it starts loosing mass centrifugally. Recycling thus takes place between a spin-up line and a point at which mass transfer started.

The problem was now that the magnetic field would be continuously decreasing so the pulsar should "drop out at the bottom". But a millisecond pulsar's magnetic field does not decay and it is estimated, fairly accurately, that all the millisecond pulsars produced in the Big Bang are still with us — so they live for ever.

In two systems, the companion is small and evaporating. It therefore seems plausible that if a pulsar is born close to a small star it feeds first and then eats the companion, cycling between a spin-up accreting phase and a spin-down feeding phase. Not a very pleasant creature.

*Part 2: Superfluid crystals*

Quantum crystals as exemplified by solid He are equally mysterious, but on a quite different scale. **A.F. Andreev** (Institute for Physical Problems, Moscow) first compared these crystals to normal ones, and to liquids. In a quantum crystal, the amplitude of the vibration of an atom is large with respect to the lattice period. De Boer working in Amsterdam in 1948 introduced the so-called quantum parameter that, for a quantum crystal, should be large, corresponding to a small atomic mass with a weak interatomic interaction. The candidates are thus $^3$He, $^4$He, $H_2$, two-dimensional quasi-cystals comprising a He atomic layer on graphite, and partially quantum crystals comprising solutions of hydrogen in some heavy metals (quantum with respect to hydrogen).

Taking solid He as the prototype, translational motion of the crystal's particles by permutation results in non-linear magnetic ordering with a first-order phase transition. Diffusion can be described in terms of $^3$He impurities in $^4$He, displaying a log-log dependence with concentration and a complex dependence with temperature, depending strongly upon the impurity concentration.

If impurities exist, why not vacancies? These have not yet been observed as the rate of vacancy tunnelling between sites exceeds by a wide margin impurity tunnelling. But their possibility brings us to the concept of zero-point vacancies, whose existence is theoretically predicted, where the vacancies are distributed over all lattice sites. A manifestation of their presence would be superfluidity caused by mass transfer *via* motion of the "vacancy liquid". This phenomena was last looked for in Grenoble in 1989 but without success, either because the critical temperature or the critical velocity is very low ($<$ 0.4 mK and $<$ 0.2Å/s, equivalent to $\leq$ 200 lattice spacings per hour, respectively).

Extending the parallels with conventional crystal growth, Academician Andreev introduced surface defects such as kinks. Non-dissipative melting and crystallization arise as the kinks move across the crystal surface. Crystallization waves develop while the surface seeks a flat, equilibrium condition. But the motion has kinetic energy that cannot be dissipated so the system oscillates. The overall effect on a $^4$He crystal gliding gently down the wall of a dewar is the remarkably skillful observation of a successive positions of the upper surface of the crystal when the dewar is disturbed momentarily.

*B. Frois stating the case for a 10 GeV electron accelerator for nuclear physics.*

### The Power Of Large Experiments

The convergence of nuclear and high energy physics continues with both disciplines seeking to push the limits of their capabilities with ever more powerful machines. In describing how nuclear matter can be probed with electrons, **B. Frois** (CEN Saclay) pointed out that the major breakthroughs in the study of many-body physics and systematic studies of nucleon, $\Delta$-isobar and meson physics in the 1 GeV range will emerge when several continuous beam accelerators come on stream in 1992 at Bonn, Mainz, NIKHEF and Bates. Europe will be well placed until 1995 when CEBAF starts operating in the USA with one variable energy beam up to 4 GeV in 1994, and with three beams in 1995 and beyond. The 12000 hours of target time each year will represent another major breakthrough.

What about a European future? The speaker argued that the most interesting next step is to resolve the structure of hadrons in nuclei by probing quark confinement and short-range interactions (for which there have already been some interesting and unexplained discrepancies with theory reported). Electrons with more than 10 GeV will be needed and they could be used to address such problems as "colour transparency" and the attenuation of hadrons. A European consensus will be required before moving forward as the machine would represent a sizeable investment. The candidates are: 1) An accelerator ring with an internal target although this would not allow a complete study of hadrons. 2) A relatively costly linear accelerator with recirculation. 3) An $e^+e^-$ collider such as an $e^-$ linac with an $e^+$ ring.

The construction, operation and first results from LEP were then presented by **H. Schopper** (CERN, Geneva). Designed as a "Z factory" to produce abundantly the neutral carrier of the weak interaction, LEP allows studies of the Z particle, and its decays to lighter particles which may include unknown constituents of matter. Concentrating on the results and leaving aside some interesting anecdotes that were recounted about the problems of building the world's largest physics experiment, Professor Schopper noted that 700000 Z events had been observed by LEP's four detectors in the 12 months since start-up in July 1989 (all other accelerators have to-date recorded 500). The machine's luminosity has increased steadily and after a final short burst of dramatic improvement in the closing weeks of the 1989/90 campaign, is now a factor 3–4 below the design goal which it is hoped to reach in 1991.

A wealth of new and detailed information has been generated, mainly because the events from $e^+e^-$ annihilation are so clean, with nearly every event being useful and interesting. Interaction energies corresponding to the mass of the Z ($91.177 \pm 0.031$ GeV/$c^2$) are in perfect agreement with the Standard Model that unifies the electromagnetic and weak forces. They are also of such precision that a first estimate of higher order corrections to the electroweak interaction will now be possible. The number of different kinds of neutrinos is placed at $2.89 \pm 0.10$ implying only three species of light neutrinos exist, a result of fundamental significance with implications in cosmology and elsewhere. With regard to strong nuclear forces, QCD predicts that the strong-coupling constant between charges of the force and the field quanta (gluons) decreases with an increasing interaction energy. The frequency with which quark-gluon pairs emit three jets of hadrons has been measured with LEP, and at lower energies at other facilities. The results show that the constant is behaving as expected.

Particle systematics predict the presence of the top quark. By incorporating results from LEP with other data, its mass is now estimated indirectly as $137 \pm 40$ GeV so it is too heavy to be found by LEP. Perhaps the most tantalizing problem in nuclear physics concerns the origin of the particle masses. Understanding on the basis of today's theory invokes the existence of the Higgs particle but theory makes no prediction as to its mass. Before LEP, no reliable experimental data was available for estimating a limit to the mass. We now know at the 95% confidence level that the Higgs's mass is between 0 and 41.6 GeV. LEP's kinematic range is almost completely exhausted until a scheduled upgrading which will extend the range by a factor of 2-3 so the search for the Higgs has ceased. A variety of so-called "superworld" particles predicted by an especially obvious extension to the Standard Model, together with other exotic particles, have been looked for without success.

The general conclusion to LEP's first year of operation is therefore that the Standard Model has proved to be unexpectedly flexible with its many free parameters. It has been able to cope with all experimental data obtained so far and there has not been that "unexpected discovery that would take us beyond the model". Foreseen experimental improvements could of course change all this.

Another of Europe's major undertakings in physics is the experimental JET fusion reactor. **J. Jacquinot** (Culham Laboratory, UK) described recent advances in the physics of magnetic confinement of thermonuclear plasma. Of the large experiments that started up in the mid-1970's to 80's, JET made the greatest step in operating performance. "Monster sawteeth" relaxation processes (identified at JET in 1986) giving sharp decreases in the plasma temperature can be suppressed using RF heating with useful increases in plasma parameters. The trend in years to come will be to increase the power handling capabilities of the limiters, and of the target plates used to anchor the plasma in the so-called X-point mode of operation, as up to now the plasma temperatures and electron densities required for ignition have only been achieved in separately in different experiments.

MHD theory has treated fairly successfully instability thresholds and plasmas at equilibrium. The theory, however, becomes *ad hoc* for large-scale birfurcation (first seen in the ASDEX reactor in 1988) and for microscopic turbulence. Insulation is lost across magnetic surfaces when "islands" are formed above a pressure threshold in high density plasmas. Experimentation is ahead of theory, especially in understanding how local particle and heat transport mechanisms affect the overall heat balance, and the stochastic behaviour between the islands. The trend will be to redress this situation. Meanwhile, scaling laws laws describing the reactor performance are available. The problem is that in applying them to new, larger experimental reactors such as NET/ITER, the conceptual design of which is now complete, is not necessarily rewarding because scaling up often introduces unforeseen instabilities.

### Cunning Experiments To Test Quantum Phenomena

**H.J. Kimble** (University of Austin, USA) described some of the interesting experiments that can be conducted using a different medium squeezed on a smaller scale, namely laser light squeezed using parametric down conversion in a cavity.

After reviewing the nature of squeezed (non-classical) light, he discussed its use to improve the resolution of interferometers by a factor of two in some cases. For quantum spectroscopy, the correct approach of using a pair of photon beams has been successfully applied to probe trapped ions. A number of important trends in the field were not covered including quiet light from non-classical lasers, quantum state synthesis, fourth order interference and the quantum limits to amplification.

*H. Walther describing his locked maser cavity and a mini-storage ring for crystallizing ions in chains.*

Traps also lay at the experimental heart of the talk by **H. Walther** (University of München) on single atom experiments and tests of quantum physics. The first topic was the one atom maser. Using a new superconducting cavity at 0.5 K, Professor Walther's group has been able to study the interaction of Rydberg atoms with a single quantized mode of a resonant electromagnetic field. The quality of the cavity is high enough to detect periodic energy interchange between the atom and the field. A remarkable result has been obtained: the maser gives non-classical radiation because the photon number distribution in the new cavity has mostly non-Poissonian statistics arising from a back coupling mechanism called quantum non-demolition.

There has already been a hint of the trend for future experiments. Quantum states between the atom and the cavity have been detected and it is envisaged that by "locking" the cavity, the group will see quantization of the entire maser system.

The speaker also described some work with trapped ions. Beautifully symmetric arrangements of 3, 4 and 7 ions extending over tens of microns were displayed and the aim is to find out under what conditions the clusters show correlated photon emission. A new experimental apparatus is being constructed for this purpose. It comprises a mini-storage ring incorporating quadrupole bending and focussing magnets and an oven for producing an ion beam. The ions are cooled using the usual laser technique (the laser beam is directed tangentially to the circulating ion beam at a point) but the scheme will allow a new limit of 6 μK to be attained. The cooled ions "crystallize" into periodic, linear arrangements. There are clearly many opportunities for experiments but these were not elaborated.

**Push Sensitivity To The Limit**

Hydrogen, the simplest of the stable atoms, permits a unique confrontation between spectroscopy and quantum theory. In reviewing the use of hydrogen's 1s–2s two-photon transition for spectroscopy, **T.W. Hänsch** (MPI Garching) pointed out that recent experiments using continuous wave longitudinal excitation of cold atom beams have attained a resolution of 4 parts in $10^{11}$, with further dramatic improvements in view. We may one day have frequency counters accurate to 15 digits on the market.

Meanwhile, some basic laws in fundamental physics can be tested with unprecedented accuracy, such as a possible variation with time of the fine structure constant. Improved values of fundamental constants will also be obtained.

In describing "particle physics at $10^{-30}$ GeV" or "atomic physics at $Z=0$", **N.F Ramsey** (Harvard University, USA) presented experiments to test time (T) and parity (P) symmetries. A sensitive test involves measuring the neutron's electric dipole moment: if it is non-zero then both T and P fail. Secondly, if a neutron does not conserve spin parity on passing through matter then only P and not T fails.

Groups at the ILL, Grenoble and the Leningrad Institute of Nuclear Science are using the current and most accurate method for measuring the neutron electric dipole which involves storing neutrons in a magnetic bottle for times approaching 100 s. This is possible because cold neutrons are totally reflected by certain materials such as copper and berylium oxide even a room temperature (which makes the experiment feasible).

But a good source of ultracold neutrons is also needed and the ILL reactor is one of the best in this respect. Neutrons with speeds up to 6 m/s (corresponding to $2 \times 10^{-19}$ TeV or 2 mK) are fed from the reactor *via* a beam pipe to a special reflecting turbine, to reduce the energy further, and then through a polarizer foil and into a 25 cm diameter, 10 cm long bottle surrounded by a coil for generating a 1 μT magnetic filed, and an outer magnetic shield. The bottled neutrons are subjected to transitions between the orientation states of spins induced using oscillatory magnetic fields and then released for analysis: the cycle is repeated by letting in more particles.

At the end of the last campaign of experiments in January 1990 the moment stood at $-(3 \pm 5) \times 10^{-26}$ e cm or an upper limit of $<12 \times 10^{-26}$ e cm at the 95% confidence level, equivalent to a bump of 10 μm on the earth's surface. The Leningrad group, using essentially the same technique but with a bottle having a split chamber, found a limit of $<26 \times 10^{-26}$ e cm.

The currently viable theory invokes supersymmetry but this could change when planned improvements and the results of a new set of experiments starting in January 1991 and ending two years later are known. The improvements involve increasing the voltage and storage volume and the use of a $^{199}$Hg magnetometer. The Leningrad group is implementing improvements as well.

Ramsey also touched upon parity violation experiments (also at ILL) where polarized neutrons are passed through metal blocks. Significant non-conserving spin rotations have been observed for several metals (with a huge effect for naturally occurring La) and they represent the first occasion in which the weak force appears to have affected a transmitted beam of particles. It is hoped to repeat these experiments with much lighter materials (*e.g. para*-$H_2$) having less complicated nuclear structure effects so as to determine directly the parity non-conserving neutron-neutron interaction.

*N.F. Ramsey (right), the 1989 Nobel laureate, is perhaps discussing the neutron's dipole moment with G.H. Stafford (left).*