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New Concepts and New Challenges

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A space traveller, nuclear physicist by education and now returning to earth from a 10 year long mission, would be highly surprised to see how his field had changed during his absence. This change has not come about by a single great discovery but rather through a broad steady progress in our deeper understanding of the nuclear system made possible by the use of new probes and detection techniques which have opened the way for the study of new phenomena. A breed of accelerators has sprung up providing beams of electrons, mesons and heavy ions with unprecedented properties. Detection methods and data handling capabilities have dramatically improved. Thus our returning colleague would learn of exciting new perspectives and plans for the future when taking a tour around nuclear physics laboratories in Europe. Here are some of the impressions he might gain.

The traditional domain of nuclear physics is the investigation of nuclear structure properties not too far away from the binding energies of the constituents. New, surprisingly simple elementary modes of nuclear excitation have recently been found. Examples are the monopole and the Gamow-Teller Giant Resonances, which are extremely coherent motions of the nucleons. The first is a compression oscillation of the whole nucleus, a "breathing mode" without a change in shape, the latter is a coherent spin-flip oscillation. By the use of heavy projectiles it has become possible to study nuclei in extreme rotational states with angular momenta up to about $50\hbar$. Crossings between many rotational bands can be observed and the change of the nuclear shape with angular momentum has been explored with amazing results. One finds, for example, states in which nucleons are aligned in such a way that the core of the nucleus is surrounded by a Saturn-like ring of nuclear matter.

Another branch of nuclear spectroscopy deals with the properties of states produced by correlated nucleons. If a particle-hole state is created in a nucleus this can lead through the residual interactions to a correlated motion affecting all nucleons. Such collective excitations can be regarded approximately as bosons. The lowest state of this kind corresponds to a surface vibration, but there can be many interacting particle-hole bosons with different angular momenta. Such excitations can be classified through symmetry principles quite similar to those applied so successfully in particle physics. As in particle physics, "supersymmetries" are being sought which allow a unified description of Boson-systems (even nuclei) and Fermion-systems (neighbouring odd nuclei). These are all examples of our effort to understand the approximate symmetries of the strongly and electromagnetically interacting many body system which constitutes the nucleus and in which the initial higher symmetries are spontaneously broken in various ways.

During his tour our visitor would learn of the wealth of information gathered in heavy ion laboratories. In nucleus-nucleus collisions, the transition from quantummechanical to classicalaspects of the process can be studied in detail.

This special issue on nuclear physics has been prepared in collaboration with the Board of the Nuclear Physics Division of the EPS. The response to our request for contributions was such that we have been unable to include all in this issue. The overspill will be published in February, notably:

Three Nucleon Forces by W. Glöcke and P.U. Sauer

Single Atom Counting with Accelerators by W. Wölfli

Nuclear physics is much to the fore in European thinking at the present time and is the subject of a report, presently in press, that has been prepared by an international group, chaired by T. Mayer-Kuckuk, for the European Science Foundation. Entitled "Nuclear Physics in Europe, Present State and Outlook", the report reviews the current activity in western Europe (on the basis of a survey carried out during 1982 and 1983) and makes recommendations for the continued development of the field.

Emphasis is laid on the value of nuclear physics as a science in its own right and, in addition, as a training ground in high technology. This underlines the need to maintain the traditional balance between centralised research on big facilities and the more modestly funded, but still important research carried out in university departments. Increased mobility of physicists is urged as is the coordination of plans for new big facilities.

The report contains details of the principal accelerators used in nuclear physics operating in western Europe and a directory of the centres of research. Copies will be available from mid-February, free of charge, on request from the ESF Secretariat, 1 quai Lezay-Marnésia, F-67000 Strasbourg.

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Heavy ion reactions provide the first example for the application of quantum statistics to finite non-equilibrium systems. The study of "cold" (non-thermalized) fusion and fission processes, interesting in itself, is also relevant to the production of new transuranium elements and possibly even superheavy nuclei. And in supercritical nuclear systems ($Z_1+Z_2>$ 137), position creation has been observed which is a signal for new phenomena such as the formation of superheavy nuclear molecules.

Eventually our colleague on his round trip would get involved in the discussion of the consequences of the discoveries in particle physics. How do quark degrees of freedom manifest themselves in a bound system of nucleons? How can the mesonic description of nuclear forces be embedded in the evolving theory of strong interaction? Are there many body forces? How can the shell-model description be reconciled with a picture of quark-bags in the nucleus? Clearly, the perspectives are changing considerably. In the past, the nucleus could be considered as a system of bound nucleons in their ground-state in a similar way that molecules and crystals are systems of atoms in their ground state. Through higher energies and probes it now becomes possible, however, to excite quark structures inside a bound nucleon. Thus the nucleus has to be described in more general terms as a multi-baryon system. It is like going from the phonon spectrum of solids to the study of electronic excitations, which, of course, are different from those of isolated atoms. These effects may be studied by electromagnetic probes like electrons and muons or by hadronic probes like K-mesons which allow a single nucleon inside a nucleus to be marked with a strange quark in a way quite similar to atoms being marked in a molecule by a radioactive tracer-atom.

In the last analysis, a nucleus would be described as a system, not of nucleons, but of quarks and gluons, although this makes little sense except for very high energy densities. The road to study such extreme conditions of matter is opened up by the developments in heavy ion physics. Heavy ions are not only a tool to excite spectroscopically interesting states and to produce new nuclides far off stability but their collisions allow us also to study the global properties of nuclear matter. First steps in this direction have been taken, but much higher heavy ion energies than presently available will be needed to force the quark-bags in a nucleus to overlap and to form a quark-gluon-plasma. Such states of matter may have existed in the first micro seconds after the beginning of the Universe.

Unavoidably our visitor would be confronted with many ideas and proposals for new facilities which are needed to take the next steps into the strange world of nuclei and their substructure. The talk would probably be about a multi-GeV high intensity electron accelerator, high precision beams for intermediate energies, relativistic heavy ion beams, the secondary beams of high-intensity proton-accelerators and K-meson factories. He realizes that bringing to life such projects in Europe would certainly depend on a substantial degree of international cooperation. For the moment, however, our returning colleague decides to read in more detail this present issue of *Europhysics News* to get more insight into some of the problems he has just heard about.

Spin Vibrations in Nuclei

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Experiments over the last few years have led to a major breakthrough in our understanding of spin excitations in nuclei. The experiments have shown that spin-spin interactions between nucleons inside the nucleus build up correlations and give rise to collective motion of many nucleons.

These findings are another demonstration of the richness of structure in the nuclear spectrum. Collective effects are observed in a variety of ways. The so-called giant resonances are examples of collective motion and have been observed in many channels: surface- and pairing vibrations, compression modes, to mention a few.

One of the first resonances to be studied in detail was the giant dipole resonance, a collective vibration of protons against neutrons. A very selective probe for the study of this mode has been the absorption of light of the appropriate wavelength.

A probe with an unexpected specificity for spin excitations has been the (p,n) reaction at intermediate energies. The incoming proton exchanges charge with the target and continues as a neutron, or, if we talk of protons and neutrons as nucleons with different isospin projection, we may also say, that isospin is transferred in the reaction. Recent experiments also show that spin is preferentially transferred; most of the outgoing neutrons have a spin direction different from that of the incoming proton.

An interesting aspect of the study of spin modes is the possible role of the internal structure of the nucleons. The simplest excitation of the nucleon is the Δ-resonance with a mass of 1232 MeV, spin $S = 3/2$ and isospin $T = 3/2$. In a quark model, the Δ is an isospin-spin excitation of the nucleon wherein a d-quark is transformed into a u-quark. We could therefore expect that in a process involving isospin-spin excitations the Δ-resonance would also be excited.

The (p,n) Experiments

The (p,n) experiments have been performed at the Indiana University Cyclotron Facility using proton beams of energies between 100 and 200 MeV bombarding targets of thickness typically 50 mg/cm². The outgoing neutrons are detected, after a flight in air of around 100 m, in large plastic detectors $15 \times 15 \times 100$ cm³. A measurement of the time of flight, derived as the time difference between a beam burst and arrival in the detector, determines the energy of the neutron. Sub-nanosecond timing is achieved and corresponds to an energy resolution of 500keV - 1MeV depending on energy and flight path. The scattering angle is changed in a beam swinger system by changing the direction of the beam impinging on the target. Despite the very small solid angle, the cross-section for the states we study is so large, it takes only about 15 min to get a spectrum. It has therefore been possible in rather short time to