IMPRESSIONS OF THE XXIX ZAKOPANE SCHOOL*

P.A. Butler

Oliver Lodge Laboratory, University of Liverpool
Liverpool L69 3BX, U.K.

It is usual for one participant of this School to be charged with the task of making 'concluding remarks' but having received this honour (or so it seemed six months before the School commenced!) I would prefer instead to give my impressions of the wonderful kaleidoscope of nuclear physics which we have witnessed during the last nine days. I will group what I believe are the key points being addressed by the lecturers into various topics in a rather simplistic approach. Let us begin with perhaps the most fundamental topic: **Nuclear Matter Distribution.** We have seen a revival of the nuclear Thomas-Fermi model presented by W. Świątecki. It is remarkable that the new formulation shows that the nuclear compressibility coefficient K has a linear relationship with the surface energy coefficient, allowing the former to be accurately determined. The model parameters are obtained by a fit to experimental data masses, giving an RMS deviation of 0.71 MeV which is comparable to the latest Droplet Model fit. Good agreement with fission barriers (very good for heavy nuclei) is also obtained. Experimental information on nuclear matter distribution was presented by J. Jastrzębski and P. Lubiński, in an elegant experiment performed using LEAR. Here radiochemical measurements are made of mass $A-1$ nuclei following bombardment of mass A nuclei with antiprotons. Such nuclei must be survivors of distant annihilation of $\overline{p}+p$ or n, with the outer nucleon at a sufficiently large radius so that the (on average) 5 pions produced in the annihilation process do not interact with the residual nucleus. These data show evidence for an enhancement of neutrons over protons at large nuclear radii ('neutron halo') which shows a strong inverse correlation with neutron binding energy while showing no correlation with B_p.

---

* Presented at the XXIX Zakopane School of Physics, Zakopane, Poland, September 5–14, 1994.

Nuclei behaviour at high spin and exotic nuclei can be grouped under the heading of **Cold Nuclear Systems** which provided a focus for lectures in the first half of the School. **Superdeformed nuclei** continue to be a fascinating laboratory of rotating spheroidal nuclei, and we saw many new experimental insights into this area of research. The large number of yrast and excited SD bands established in the mass 150 and 190 region have enabled the following question to be answered: is the observation of pairs of 'identical bands' expected on a purely statistical basis? The answer given by F. Stephens is surely **no** in the mass 190 region. This is perhaps surprising since the inclusion of pairing in any theoretical description would probably wash out such effects. For the mass 150 region Z. Szymański provided a nice theoretical description based on the pseudo-spin scheme which offered explanations for several observed pairs of identical bands. The peculiar effect of bifurcation, or $\Delta I = 4$ staggering, observed in some SD bands was discussed by M.-A. Deleplanque, who speculated on the existence of a Y_{44} term in the nuclear Hamiltonian to give the required invariance of the nuclear wavefunction under a rotation through 90°. Some progress in the theoretical description of this effect was reported by P. Magierski whose interaction included the necessary $Q_4.Q_4$ term. M.-A. Deleplanque also reported on the observation of the linking transitions between the highly deformed ('hD') band in ^{135}Nd and the normal states where lifetime measurements also exist. The observed hindrance for transitions from the lowest states is expected if their wavefunction becomes mixed with normal as well as hD components, as a result of the gamma-driving properties of some orbitals occupied. A status report on the findings of the Legnaro group on linking transitions in ^{137}Gd, ^{137,139}Sm and ^{139}Gd was given by C. Rossi-Alvarez. For SD nuclei, R.M. Lieder has determined the sum energy of pairs of such transitions deexciting the SD band into normal deformed levels in ^{144}Gd which are individually unresolved because of the large number of intermediate states. He also showed that the SD band in this nucleus contains a beautiful example of a pronounced band crossing, caused by the alignment of a pair of $i_{\frac{13}{2}}$ protons. In moving from exotic shapes to exotic nucleon mixtures it is exciting to see that new information is now becoming available on heavy **neutron rich** systems. B. Fornal narrated how γ-ray spectroscopy techniques are being applied to the study of neutron-rich projectile-like fragments formed in multi-nucleon transfer reactions (MNTR). As an example of this technique the value of $B(E2; 10^+ \rightarrow 8^+)$ could be measured for the heavy Sn isotopes and hence the occupation of the $h_{\frac{11}{2}}$ neutron orbital be mapped across the range of A from 116 to 132. Also reported was spectroscopy on the very neutron rich system ^{68}Ni populated by MNTR (Fornal) and in heavy Yb nuclei (Stephens). Advances in spectroscopic techniques in neutron rich nuclei were also advertised by groups studying fission products:

M. Bentaleb described the level scheme of ^{142}Xe while G. Smith discussed a novel application of the DSAM lifetime techniques to nuclei such as ^{156}Nd recoiling isotropically in the fission process. For nuclei with $Z \approx 50$ R. Julin described the role of intruder states, while for very **neutron deficient** nuclei H. Grawe displayed the results of systematic studies of nuclei near $N = Z = 50$. He showed that the separation of single particle states $g_{\frac{9}{2}}$, $p_{\frac{1}{2}}$ below the shell gap at $N = Z = 50$ is similar for both protons and neutrons, while the separation of the $d_{\frac{5}{2}}$, $g_{\frac{7}{2}}$ orbitals above the gap is very different. Comparisons with models assuming different potential forms indicate that the Woods-Saxon potential apparently gives the wrong Coulomb shift for particle states in the continuum for this region of the periodic chart. In the study of **heavy nuclei**, fission can dominate the total reaction cross section and various techniques were reported which improve the signal-to-noise. K. H. Maier described a highly efficient CN recoil detector which enables coincidence gamma-ray spectroscopy to be performed; examples were shown for neutron deficient At isotopes. In the quest for heavy nuclei produced with much smaller cross sections, M. Leino showed how the RITU gas filled magnet separator at Jyväskylä, used in conjunction with Si strip alpha detectors, identified 10 new isotopes in the At-Th region close to the proton drip line. The question was posed whether such techniques could be applied in the search for SHE with $Z \approx 110$, with $\sigma \approx 1$pb. Of possible relevance to this question is the observation by A. Maj in GDR studies that fission decay is a non-statistical process with lifetime $> 10^{-21}$s.

Moving on to **Nucleus-Nucleus Collisions** we saw how detailed measurements performed at Legnaro of sub-Coulomb cross sections or gamma multiplicities can lead to the determination of the barrier height distribution $D(B)$ using the 'Rowley' formulation $\sigma(E) = \int \sigma(E,B)D(B)dB$ where the function $D(E)$ is determined either from the quantity $d^2(E\sigma)/dE^2$ (A. Stefanini) or from $d\langle \ell \rangle/dE$ (D. Ackermann). The function $D(E)$ is very sensitive to the nuclear shape, e.g. both magnitude and sign of β_4 can be determined, the former rather accurately. For more energetic systems M. Kicińska-Habior reported on recent measurements on Ultra Dipole Radiation, i.e. on high energy (30 - 40 MeV) gammas emitted by bremsstrahlung in the collision process. The experiments provide conclusive evidence that the accelerating particles which give rise to UDR are nucleons rather than the nuclei involved. Comparison of the yield for systems with a different number of neutrons (^{24}Mg and ^{26}Mg) suggest that the phase space distribution is important in this process. In a slightly different context (higher energies) G. Wolf discussed the importance of $(p-n)$ interactions in a thermalized system in providing a source of high energy photons (rather than from first chance collisions), which may yield information on the nuclear equation of state (see later). A very different method of injecting energy into a nuclear system was presented by A. Trzcińska (see also the lecture by J. Jastrzębski) in which the annihilation products from the interaction with 1.2 GeV antiprotons can inject 150 MeV into the nucleus without compression or angular momentum. The temperature of the system seems to be higher (as evidenced by radiochemical measurements of the mass loss of reaction products) than that obtained using 'conventional' projectiles. In the subsequent discussion it was suggested that this might provide a convenient way to study GDR processes. These and other **Decay Processes** were the subject of several lectures and contributions. G. Viesti reported on measurements of the level density parameter deduced from the energy spectra of evaporated charged particles, looking for evidence that this undergoes a transition between $A/a = 8$ MeV and 15 MeV at a particular value of temperature which is mass dependent. He also observed that for one particular nuclear system (^{152}Dy) there is no dependence of the proton spectra on the final state deformation - oblate, prolate or SD. For statistical γ-ray emission J. Rekstad displayed the results of a careful set of measurements on first generation γ-ray emission from the reactions ^{163}Dy(^{3}He, αxn) $^{162-x}$Dy. Two surprises seemed evident. Firstly the inability to describe the spectral shape either with or without pairing, and secondly the appearance of a peak at 2.5 MeV which is clearly non-statistical in nature. The occurrence of unexplained γ-ray peaks was also reported by R. Betts as a by-product of the APEX early searches for $e^- - e^+$ peaks in very heavy collisions - what is the origin of a transition (or several transitions) of energy 1.8 MeV in ^{238}U, far from the collective structure? A systematic study of the decay of the GDR built upon excited states was presented by A. Bracco, who showed that the observed variation of FWHM with spin measured simultaneously with the (energy dependent) angular distribution of the emitted radiation, could only be explained by shape and orientation fluctuations in the hot system and is not due to changes in the collisional damping effects (intrinsic width). Previously observed dependence on the entrance channel for the shape of the GDR spectra appears to be in doubt according to the work of D. Fabris, who showed very clearly that in Ni induced reactions the spectra can be reproduced using standard statistical parameters just like in the case of more mass-asymmetric reactions. Jumping from ≈ 10 MeV/u to ≈ 1 GeV/u **relativistic collisions** G. Wolf introduced one of the *raisons d'être* for such studies - the exploration of the nuclear equation of state and determination of nuclear compressibility for nuclear densities much higher than the equilibrium value discussed by W. Świątecki and probed by studies of the GMR. He reported on progress in the development of the BUU transport model, which can be used to extract information about the initial state in these collisions from measurements of the final state. Two very interesting 'EMC'-like effects are evident in the SIS studies of hadronic systems. R. Simon showed results from TAPS measurements of enhancement in the yield of $\pi \rightarrow \gamma\gamma$ for the systems Au+ Au compared to that for Ar + Ca at small p_t values, which is evidence for a medium effect. E. Grosse described the striking correlation of sub-threshold K^+ production (relative to π^+) with the number of particles in the interacting system. The 'strangeness suppression' for small N (Ne+NaF in this case) is in line with other strangeness production data but what is new here is the observed enhancement of K-production for the much heavier system Au+Au.

The pickings of the choicest fruit of experimental findings and theoretical developments is a very subjective task and I make no apologies for my selection, yet my task would not be complete without selecting other examples which will ripen in the future. There is eager anticipation that the fantastic equipment developed at COSY will yield new results from the studies of nucleon-nucleon and nucleus-nucleus scattering near the meson production threshold. To give but two examples discussed by K. Kilian, H. Machner and J. Speth, (i) the production of pions almost at rest from collisions slightly above threshold should enable the study of deep states in pionic atoms (e.g. $^{39}Ca^*$) enabling the investigation of the little known $\pi - A$ interaction; (ii) the study of $pp \rightarrow ppK^+K^-$ will probe meson-meson interactions in the final state. Heavy meson exchange has already been shown by H. O. Meyer to play an important role in $pp \rightarrow pp\pi^0$, in pioneering experiments which exploit the stored, cooled beams developed at IUCF. He also described the progress in the development of polarized beams and target necessary to probe axial currents in Gamow Teller transitions in $pp \rightarrow pp\pi^0$. Meanwhile for nucleus-nucleus collisions in SIS, new results on K production from the KaoS spectrometer (E. Grosse) are eagerly awaited, while the speculations that studies of the $\omega \rightarrow \pi^0\gamma$ process will probe the collision region and that the $\Delta \rightarrow N\gamma$ reaction will be enhanced in the compression phase (R. Simon) will surely be investigated soon. For much cooler systems W. Nazarewicz has presented a 'superfamily' classification of nuclear shapes which predict, for example, that there are accessible states in ^{232}Th having both hyperdeformation and a large degree of reflection asymmetry, as evidenced by fission resonance studies. Evidence for an extremely exotic shape in nuclei, the linear six-alpha chain in ^{24}Mg, was presented by R. Betts and surely there will be new measurements on such systems. W. Świątecki discussed the possibility of cavitation inside nuclei although this is not expected for cold systems until $Z^2/A = 100$. W. Gelletly perceived the path to $N = Z$ nuclei beyond ^{84}Mo as either on a route of more sensitive apparatus (the production cross section rapidly dips below 1 μb) or by enhancing the cross section by the use of radioactive beams. The former method might be accomplished soon, while the second awaits development in the area of technology such as the RIST project in the UK. As the final advocatory word from 'Memphisto', who happens to be a gamma-ray experimental spectroscopist, I was slightly disheartened to listen to B. Herskind's observation that nuclear decay schemes will rapidly become very complex for energies $\approx$ 1 MeV above the yrast line at the onset of rotational damping. Nevertheless it is clear that the order-of-magnitude increase in resolving power of the new γ−ray microscopes Gammasphere (to be completed in 1995) and Euroball III (1997) will allow them to probe the average properties of the microstructure in hot rotating systems as well as quantal structures with conserved quantum numbers along the cold yrast line all the way to I=60 $\hbar$. We await the discovery of many new phenomena and impatiently look forward to the next School!