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CONCLUDING REMARKS : SOUVENIRS DE PARIS '90

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Résumé - Réflexions personnelles a partir de la septième conference internationale sur les phénomènes de polarisation en physique nucléaire.

Abstract - Personal conclusions drawn from 7th International Conference on Polarisation Phenomena in Nuclear Physics.

1 - INTRODUCTION

The conference banquet was held in Vincennes near the place where Louis IX was reputed to have dispensed justice in the 13th century. Now justice, unlike truth, has a certain amount of arbitrariness depending upon the biases of the judge. The same is certainly true of any conference summary talk where an instant decision is called for, as from a World Cup football referee. Seekers after truth would do better to wait for the appearance of the full proceedings.

It is nevertheless apparent that the average energy of the nuclear reactions discussed at the meeting, especially in the invited papers, has increased significantly since Osaka. Though this may reflect mainly the preferences of the organising committee, the trend seems likely to continue, whether or not future conferences in this series are held in collaboration with the High Energy Spin Physics meetings.

2 - TECHNOLOGICAL PROGRESS

As a theoretician it seems to me that technological progress over the last five years has been significantly greater than theoretical, and experimentalists are to be encouraged to keep up the good work! In fact I shall devote almost all of my talk to experimental progress. A trivial example of this is the Beurtey-Saudinos wheel. In order to make simultaneous observations of $A_y$ in proton-proton elastic scattering at many different energies, the L.N.S. laboratory constructed an energy degrader with many steps which looks something like a circular Escher staircase. This rotates fast in the beam and high statistics data can be obtained in 16 different energy bins at one setting. The preliminary data taken last week quickly killed off one dibaryon candidate /1/.

On a more long term level, the progress on polarised sources and targets is very impressive. Häusser and Leduc presented alternative approaches for the production of $^3$He targets. The theoretical interest in these is enormous since they will provide high neutron polarisation combined with low proton polarisation which is ideal for the study of spin-dependent deep-inelastic neutron structure functions. The TRIUMF target is based upon spin exchange with one part in a million of Rubidium but with a serious contamination of Nitrogen which contains almost as many unpolarised neutrons as polarised ones in the $^3$He. However it leads to a target with a high density. This has been tested in $^3He(\vec{p},\pi^+)^4He$, where $A_{nn}$ must be unity, and more interestingly in the $^3He(\vec{p},pp)$ quasi-elastic scattering. As expected, $A_{nn}$ in the latter is small due to the target protons being weakly polarised. The observed signal is mainly sensitive to the $S'$ mixed-symmetry states. The $(\vec{p},pn)$ data will show much more significant effects.

The Paris approach is very different and relies on metastability exchange with $^3He(2^3S_1)$, yielding a target of much greater purity. Though, as Willy Haeberli remarked as he was leaving before the concluding session, polarised $^3$He targets are not new toys. It is just that their time has come and we are now spectators (or participants) in what Holt calls a $^3$He target war whose outcome might depend upon the particular experiment under discussion. Independent of who wins this, I found Mme Leduc's talk, where she discussed...
among other things collective phenomena associated with ensembles of $^3$He at low temperature, one of the most fascinating of the whole meeting. The p-T phase diagram changes according to whether the $^3$He sample is polarised or not.

3 - THE DEUTERON FORM FACTOR

There has also been much progress on polarised internal gas targets and Steffens and Holt reported on storage cells for H and D with $10^{14}$ particles/cm$^2$ rather than the $10^{12}$ of a free jet. At some point this may be competitive for the measurement of the deuteron form factor. To separate the central and quadrupole form factors $G_c$ and $G_Q$ of the deuteron one must either measure the tensor polarisation or analysing power in elastic scattering, i.e. either $ed \rightarrow e\tilde{d}$ or $e\tilde{d} \rightarrow ed$. The polarimeter approach seems as yet better than that of the polarised target and the first results of the Bates measurement were described by Garçon. In this experimental tour de force values of $t_{20}$ have been found out to $q \sim 4.5$ fm$^{-1}$. Analysed in impulse approximation the data seem to show the node in the monopole form factor for the first time, though the error bars are still large. It should be noted that there are large cancellations between meson exchange currents and relativistic effects but as yet nobody has put the two consistently together for this data.

Such experiments are starting to test significantly the NN force at short distances and they need to be pursued further. The AHEAD polarimeter used here is based upon the large analysing power found in dp elastic scattering but this falls off sharply above about 200 MeV. One alternative is to use rather a polarimeter based upon the deuteron charge exchange reaction $dp \rightarrow (pp)n$. A Grenoble group /2/ has found useful tensor analysing powers combined with sizeable cross sections at both 200 and 350 MeV. As an example I show the angular distributions of $A_{xx}$ at the higher energy, binned in intervals of the excitation energy $E_x$ in the (pp) system.

![Angular distributions of $A_{xx}$](image.png)

Fig. 1 - Tensor analysing power $A_{xx}$ for $dp \rightarrow (pp)n$ at 350 MeV binned in intervals of $E_x$ as a function of momentum transfer /2/. The curve represents an impulse approximation calculation.

Providing the two protons are detected in the peak of the $^1S_0$ final state interaction then the $(d,2p)$ reaction is a good probe of $\Delta S = 1$, $\Delta T = 1$ transitions. It was shown however in Sakai’s talk that the same is also true of the $(\tilde{d},pn)$ reaction. The peak width of the $^1S_0$ final state is about 60 KeV which is much narrower than that of $^3S_1$ so that the triplet final states can be eliminated by good energy resolution.

A deuteron tensor polarimeter which works at intermediate energies is required for the study of many other reactions. Morlet /3/ showed the first data on spin transfer in $(\tilde{d},d')$ reactions at 400 MeV. The primary aim of this experiment was a search for a signal for $\Delta S = 1, \Delta T = 0$ transitions in nuclei. For this one really needs to separate $m = \pm 1$ states of the deuteron from $m = 0$ both initially and finally. This of course requires a tensor polarised beam and polarimeter. However the group showed that with only a vector polarimeter they could, within certain approximations, find a useful $\Delta S = 1$ signature which works well on the first few levels of $^{12}$C. Using this, they found significant $\Delta S = 1$ isoscalar strength above 18 MeV. To get absolute values of spectroscopic factors however they need to normalise the data with a measurement of $t_{20}$ using a recoil polarimeter.
4 - CHARGE SYMMETRY

Another class of polarisation experiments which requires enormous persistence are tests of charge symmetry in neutron-proton scattering. Years of struggle have brought one new measurement of the comparison of $A_\pi$ for $\bar{p}p$ and $np$ elastic scattering at 183 MeV /4/. The analysing power difference of $\Delta A = A_n - A_p = (3 \pm 0.6) \times 10^{-3}$ is in accord with microscopic models, with the biggest contribution to the symmetry breaking coming from $\rho - \omega$ mixing.

I would like to suggest that such experiments be carried out at much higher energies, $\sim 1.2$ GeV, i.e. near the threshold for $\eta$ production. In this region the amplitude for $\eta$ production is much bigger than that for $\pi$ production due to the influence of the $N^*(1535)_{111}$ isobar. Thus all the vertices in the box diagram of figure 2a are strong so that the result will reflect the large $\eta - \pi$ mixing matrix element. External $\eta - \pi$ mixing of figure 2b could also lead to effects of the order of a few percent in the forward/backward asymmetry in $np \to d\pi^0$ due to the large $\eta$ production near threshold /5/.

![Diagram](attachment://diagram.png)

Fig. 2 - Some diagrams contributing to charge symmetry breaking near the $\eta$-production threshold in (a) $np$ elastic scattering and (b) $np \to d\pi^0$ due to $\eta - \pi$ mixing.

5 - DIRECT AMPLITUDE ANALYSIS

Detailed measurements of many spin-dependent quantities often allow for a direct reconstruction of the scattering amplitudes without having to pass through a partial wave analysis. This is particularly useful when there is much data over a limited angular domain. Several examples of this approach were given.

i) $pp$ elastic scattering. In his talk Lehar stressed that above 1 GeV, phase shift analysis becomes progressively more difficult but that direct angle-by-angle amplitude analysis had been done at several energies up to 2.7 GeV. In general there are two types of solution, only one of which agrees with phase shift analysis below 1 GeV.

ii) $pp \to \pi^+d$. There has been a direct reconstruction by the Geneva group up to 580 MeV /6/, though Bugg's phase shift analysis gives rather similar answers. Things become particularly simple very close to threshold and TRIUMF have reported a measurement of $A_\eta$ in $\bar{p}p \to d\pi^+$ only 3 MeV away from there /7/. Combined with their earlier $np \to d\pi^0$ cross section data this shows that the $(\ell_\pi = 1, \ell_p = 0)$ amplitude is negligible.

iii) $^{16}O \to p'^{16}O(O^-)$. There are only two invariant amplitudes for such a transition and these can be written in the form $A_\pi \vec{q} \cdot \vec{q} + A_K \vec{q} \cdot \vec{K}$. Thus measurements of $\sigma$, $A_n$ and $D_m$ can determine everything up to an overall phase. The results of an Indiana measurement /8/ were mentioned in Stephenson’s talk. From this it is clear that the phenomenological analysis runs into difficulties with the $A_K$ amplitude. This is valuable information as to where theoreticians should look to improve their models.

Despite all this talk about amplitude analyses, work on optical models (Schrödinger or Dirac) is still necessary to describe data in the majority of cases. As an example of this let me cite the work of Kelly /9/, discussed in Stephenson’s talk, where a mass of transition data induced by few-hundred MeV protons has been systematically analysed in terms of effective interactions.
6 - SEMICLASSICAL DESCRIPTIONS

A theory becomes more understandable, and somehow more believable, if it is close to a semiclassical limit and this is often the case for tensor observables in heavy ion scattering. Fick showed some of the data on the scattering of polarised \(^6\)Li, \(^7\)Li and \(^{23}\)Na in the range of 10's of MeV per nucleon. Here approximate tidal symmetry gives relations between \(t_{50}, t_{21}\) and \(t_{22}\), though it still needs coupled channel computer codes to get the fine details right. An interesting insight into these tidal symmetry ideas has been provided through the scattering of polarised \(^5\)Li ions from \(^{64}\)Fe at 70 MeV /10/, extending the model into the Fraunhofer region.

Ishihara disclosed that boron fragments produced by the \(^{197}\)Au(\(^{14}\)N,\(^{13}\)B) reaction at 40 MeV per nucleon are polarised to an amount proportional to the Fermi momentum of the \(^{12}\)B inside the \(^{14}\)N. He had the satisfaction of showing that a semiclassical picture describes this well. Hence the phenomenon is likely to be extremely common, holding up the possibility of providing beams of polarised (un)stable nuclei.

It was reported by Sakai that data on \(^{66}\)Zn(\(d,p\))\(^{67}\)Zn show far side dominance but that one definitely needs far-side/near-side interference in order to reproduce the fluctuations /11/.

7 D-STATES

Lehman described to us the theoretical and experimental state of the asymptotic D/S ratio \(\eta\) in light nuclei. Whereas the overall situation is very satisfactory for the partitions d:pn and to a lesser extent \(^3\)He:dp/\(^2\)H:dn, the \(\eta\) for \(^4\)He:dd is still poorly known as it is for \(^6\)Li:da. On the other hand nothing is known at all experimentally on \(^6\)Li:3He:\(^3\)H. An analysis of \(^6\)Li → \(\alpha\alpha\) at 10 MeV suggests that \(\eta_\alpha \sim -0.2\) and \(\eta_{\Delta} \sim -0.01\) /12/.

It might be worth investigating whether the new polarised \(^6\)Li beam at Saturne, with an energy up to about 1 GeV per nucleon /13/, could be used for investigating D-states. One could either study the \(^6\)Li\(d → \alpha\alpha\) reaction again or look at the stripping reaction \(^6\)Li\(p → d\alpha p\) and measure the final deuteron polarisation.

It was shown by Soffer and Jaffe that there is no real evidence for D-states within the 3-quark decomposition of the proton; the spin crisis can be explained in other ways. It should of course be noted that for the case of the \(\Delta\) the decay into the \(\pi\p\) channel automatically mixes in some small D-state components in the quark sector.

8 - HIGH ENERGY EXPERIMENTS

It has been known for many years that \(\Lambda\)'s produced inclusively in high energy reactions have a strong negative polarisation. This is easily observable because the polarisation is automatically analysed through the \(\beta\)-decay of the \(\Lambda\). This is exactly the same trick that Ishihara uses to show that his \(^{12}\)B fragments are polarised. This work has now been extended to other hyperon and antihyperon production in \(p Be → H(\bar{H})X\) and Heller showed us data for \(\Xi (P-ve), \Sigma (P +ve)\) and \(\Omega (P-0)\). All these results can be explained in terms of a naive quark model. This also accounts for the polarisation of the \(\Lambda\) being approximately zero since there are no spectator quarks carrying spin information from the incident proton to the final antihyperon. However he also revealed that the polarisation of the produced \(\Xi^-\) is significantly non-zero and is in fact similar to that of the \(\Xi^-\). One is thus left clutching at such straws as the suggestion that it is rather the gluons which remember the direction of the reaction plane.

Jaffe reviewed the spin-dependent deep inelastic structure function \(g_2(x,Q^2)\) which is a 'unique probe of quark-gluon correlations'. This might be measurable through \(\bar{e}\p → eX\) with Hermes @ HERA though it requires the protons to be transversely polarised. He reminded us of the Burkhardt-Cottingham sum rule

\[
\int_0^{\infty} dx g_2(x,Q^2) = 0
\]

which could play a crucial role in the analysis of the Hermes data. Theoretically it is still far from clear whether this sum rule should be valid or not. I used to play bridge quite extensively with these two authors and I always treated any of their bids with suspicion!
9 - ANTIPROTONS

With the exception of $\Lambda\bar{\Lambda}$ production /14/, where there is self-analysis of the strong final polarisation, experiments on antiprotons at LEAR have generally been confined to measurements of cross sections and proton analysing powers for $\bar{p}\bar{p}$ elastic, charge exchange and annihilation channels. Bradamante referred to the problems of fitting simultaneously $A_\gamma$ for elastic and charge exchange scattering within a potential model.

Much of the insight into the pp system has been obtained by measuring two-spin correlations or transfers and it is very heartening to learn that polarised $\bar{p}$ and $\bar{n}$ beams are close to reality and that correlation data will be available for the next conference.

10 - SPIN-ISOSPIN RESPONSE FUNCTIONS IN NUCLEI

There are now ($\bar{p},\bar{p}'$) spin transfer experiments to the continuum available over a wide range of energies and, as Baker stressed, the longitudinal and transverse response functions $S_L$ and $S_T$ are now well separated in, for example, $^{40}\text{Ca}(\bar{p},\bar{p}')$. I had not realised before that Fermi averaging had a much larger effect on $S_T$ than $S_L$. Anyway we are approaching the point where the enhanced $\Delta S = 1$ response is understood'. Furthermore, it is now possible to extract multipole strengths for $\Delta S = 1$ as a function of $\omega$.

The isospin-one exchange is not in such a good shape, though it has been investigated in the $(\bar{d},2p)$ reaction /15/. There is longitudinal/transverse separation up to the $\Delta$ region and it is seen that the response is much more transverse for $^{12}\text{C}$ than for hydrogen.

11 - POT-POURRI

Conferences are important for the little snippets of information which one picks up. They may turn out to be canards or little gems.
i) Arndt's suggestion /16/ from the analysis of 2 GeV pion- nucleon scattering that the $\pi NN$ coupling constant might be significantly lower ($\approx 5\%$) than the usually accepted value ($f^2=0.075$ rather than 0.079). Note that this comes in squared in the $np \rightarrow pn$ cross section so that it could affect many calculations if it were true.

ii) Electron distortion is crucial in order to get the right spectroscopic factors in $(e,e'p)$ reactions off heavy nuclei.

iii) Simonov proposed that the Pomeron might be associated with two-gluon exchange and hence with glueballs. This may not be too relevant for medium energy pp elastic scattering since the inelasticity is mainly dominated by $\Delta$ production generated by $\pi$ and $\rho$ exchange. In order that these ideas are valid we might have to go up to a region of energies where isospin-one exchange is small in the inelastic amplitudes.

iv) Jaffe made the point that if there is quark deconfinement in a nucleus with spin-1 or higher then there will be higher order structure functions. These look rather like meson exchange current contributions but I doubt very much whether they are of any significance for the deuteron target since it is so diffuse.

12 - DIBARYONS

I have come under intense lobbying from Nefkens and Huber to publicise the Paris Declaration on the strengths of dibaryon claims that came out of the discussions in parallel session A. It is possible that their statement is too simplistic since there is a real Physics problem associated with wide dibaryons. Resonances often come near threshold, e.g. the N* (1535) at the $\eta N$ and the $S^*$ at the $\bar{K}K$ thresholds. If there is some overall attraction then the opening of the new channel just fixes the position of the resonance.

On the other hand there are often loops in the Argand diagrams which are reflections of the dynamics, but without the presence of a nearby resonance, much like the Schmidt loops in $\pi N$ scattering of a generation ago. As a consequence I think we could, at present, refer to it rather as the Nefkens-Huber declaration.
13 - FAREWELL

Having worked on the viewgraph sheets overnight, I realise that the result does not correspond to a fair survey of the total input to the Conference. The things that have stuck in my mind are almost exclusively the experimental results. Worse than this, I noted down many things because I could relate them to other things I already knew. Though my choice might be seen to be a little arbitrary, like Justice (or a World Cup Referee) it will be seen to have been biased in favour of the local rulers (or football hooligans). Presumably this can be righted when we meet again in four years time (in Bloomington?). Until then let me repeat once more to the experimentalists that they are doing a great job!

I would like to thank all the speakers who aided me, especially those who sent me material before the meeting. The Conference organisers, in particular Alain Boudard, have been most helpful to me and other participants. The generous financial help given to many of the younger physicists is very much to be welcomed. Finally let me acknowledge support throughout the meeting from Nicole Guillot and Jean-Philippe Santucci.

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