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CONCLUSIONS OF THE CONFERENCE

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Which is the "correct" way to view the nucleus? Should we view it as a system of nucleons interacting by two-body potentials from NN scattering? Should we view it as a system of interacting quasiparticles? Is it more "correct" to discuss it in terms of $\pi N A$ degrees of freedom? Is it not more "fundamental" to take the approach that the nucleus is a system of quarks? What is right? What is the "truth"?

The truth is that nuclear physics corresponds to a whole spectrum of viewpoints which depend on the framework and scale. It all depends on how one looks at the problems and on what is emphasized. This has come out well during this conference. The discussion has ranged from classical nuclear physics to quarks, with the main emphasis on the interface region in between. Interesting and important progress has been reported in all these areas.

The nearly classical modes of collective excitations of nuclei have been vigorously investigated for a very long time. The textbook example is the giant dipole E1 resonance in which neutrons and proton oscillate against each other. Even in this well-explored field there are still new features: Lo Iudice and Palumbo¹ predicted, a few years ago, that in a deformed nucleus the neutrons and protons could beat against each other in a scissor-like mode corresponding to a magnetic M1 excitation (Fig. 1).

FIGURE 1

THE NEW M1 SCISSOR MODE

This mode is now reported by the Darmstadt group²; it is seen very clearly and the M1 excitation can be identified as due to the orbital motion. As expected on this level, the truth is thus that nuclei are chunks of proton-neutron matter. At this point it is relevant to raise the question of the validity of the nuclear shell model in regions of high nuclear density. How well does the nucleonic single particle description work under such circumstances? The central region of nuclei near lead is about as dense an environment as is encountered anywhere in stable nuclei. If the shell model picture breaks down because the density becomes too high this is the obvious place where effects should show up. The probability distribution of the shell model $3S_{1/2}$ orbital can be explicitly constructed from electron scattering experiments in this region without model assumption^{3,4} (Fig. 2). The result clearly exhibits the characteristic shape of the 3S-wave function with a strong peak in the high density region near the origin. This provides very strong direct evidence for the nucleonic picture of nuclei at nuclear matter density. There is no real evidence of any breakdown of this picture, although there is an observed 30% reduction in the strength of the 3S state. This is one of the most important experiments in nuclear physics in the last few years, and it has been referred to repeatedly at this meeting.

FIGURE 2

that this interaction is a dipole-dipole interaction akin to the ordinary hyperfine interaction. As a consequence, it only contributes in second order to the binding.

On the experimental side we heard about important new information concerning the α -particle. It is now firmly established that the α -particle is a deformed nucleus. The evidence comes both from old $(\vec{d}, \alpha)$ data on heavy nuclei⁷, but in particular from a beautiful and easily interpretable measurement of the tensor asymmetry in the $\vec{d}d \rightarrow \alpha\gamma$ reaction⁸. The rather large asymmetry indicates about 10% D-state admixture in the α -wave function with a sign and magnitude consistent with the deuteron D-state and due to the OPE dominated tensor force.

The configuration responsible for the D-state is that of two aligned deuterons (see Fig. 3). This discovery must clearly be followed up much more

FIGURE 3

in detail both experimentally and theoretically. The four-body calculations give α -particle wave functions which to 50% are $d+d$, when projected onto this channel, and with high probabilities for $p+t$ and $n+^3\text{He}$ as well. There are clearly strong reasons to investigate the detailed validity of these suggestions, e.g., by quasielastic electron scattering on these cluster structures. The occurrence of a rather strong deformation means also that the question of possible rotational states in the excited spectrum should be carefully examined.

The α -particle deformation is also important in the perspective of heavier nuclei, since the α -particle is a specimen (although a poor one) of nuclear matter. Its D-state is a vivid experimental reminder of the great importance of tensor forces and deuteron-like correlations in all nuclei.

The second advance in our understanding of the light nuclei concerns the dip in the ^3He nucleon distribution near the centre (Fig. 4). This feature became apparent a couple of years ago and it has defied a satisfactory explanation since. Even quark physics has been suggested as a possibility. Pandharipande⁵ showed us that if the anomaly is assumed to be a two-nucleon effect, the corresponding ^4He anomaly can be described in terms of ^3H and ^3He experimental data. This observation strongly limits the search for possible explanations.

In this perspective we learn experimentally that it is a "truth" that nuclei consist of nucleons even in their densest regions. The nucleons in the nucleus are of course in interaction. It is then tempting to see how far one can get simply assuming them to be without structure, but interacting via two-body potentials. This programme has been a major part of nuclear physics for decades. A very great effort has been made determining such two-body potentials from NN scattering consistently with phase shifts and one-boson exchange descriptions. There have been great theoretical difficulties introducing these potentials into the scheme, not conceptually, but in carrying it out practically to high numerical precision. Pandharipande⁵ reported that in the last few years the situation has stabilized: the $A = 3, 4$ and ∞ systems can be reproducibly calculated from two-body potentials v_{ij} using a variety of quite different techniques. The results agree, so the problem is technically in hand on the two-body level. This is the case not only for binding energies, but also for wave functions.

What do we learn from this ? First, for two-body potentials of one-boson-exchange type consistent with NN interactions, and most importantly, consistent with the deuteron properties, the binding energies of both the few nucleon systems and nuclear matter come out within a couple of MeV of experimental values independent of the detailed parametrization. The theoretical results are almost independent of the parametrizations. The remaining discrepancies do not reflect two-body physics, at least not two-body physics on the level of potentials. They signify new physics, so we will return to this point in a moment.

The main results have several important messages:

- First, the nucleon-nucleon two-body potential approach works extremely well. In fact it works much better than one would guess just looking at agreement with data. The reason is the large cancellations between the terms from the kinetic energy repulsion and the average potential attraction: the results for binding energies result from differences between large numbers. On the right scale the results are good to a few per cent!

- Second, it is clearly seen in such calculations that the result is insensitive to the short range of the NN force. The few-nucleon systems and nuclear matter have essentially the same short range correlations as in the deuteron. In the two-body approach the short range phenomena are already included by known aspects of the NN interaction and we learn little more about them in complex nuclei.

- Third, these calculations bring out very strongly that the main feature of the binding interaction is the tensor potential dominated by the OPEP tensor part, just as is the case also for the deuteron⁶. It is interesting to note

FIGURE 4

While these investigations emphasize the success (the "truth") of the nucleon picture with potential interactions, it also makes failures of this description very significant. At this point, it becomes natural to go outside the approximation of inert nucleons: it is well known from condensed matter and molecular physics that three-body forces are induced by the polarizing effects of the exchanged quantum in the medium. As a consequence it is natural to induce three-body forces in nuclei for example by a pion rescattering on an intermediate nucleon (Fig. 5a) : the important

contribution is due to the p-wave rescattering since the s-wave rescattering term is suppressed in analogy with πN scattering. (Technically, the s-wave suppression is due to chiral symmetry.) At present, we can conclude the following: this natural mechanism for a three-body force goes in the right direction in all cases, but its effect is a bit too strong in the binding. It must be tempered: the short range attraction is somewhat too strong. The exact mechanism for this is still under discussion, but the contribution from the Δ -interaction term (Fig. 5b) seems an important ingredient. It is unlikely that this question can be cleared up from binding energies alone. However, it

TWO IMPORTANT 3-BODY FORCES

FIGURE 5

is important to realize that the three-body force has a geometric structure differing from the two-body one. This leads to an enhancement of normally small components in the $3N$ -wave function. A special effort should be made to find out the experimental signatures of these components. Only in this way, is it possible to get the additional information which would transform the three-body explanation for the binding energies from plausibility to a demonstrated fact.

At this point the issue of the structure of the nucleons in a nuclear environment begins to emerge more seriously. Such an effect is difficult to disentangle from nuclear structure in individual transitions unless the situation is particularly favourable. As a consequence, sum rules and response functions become interesting instruments for exploring medium effects on the nucleon structure on the one hand, and for studying correlations in the nuclear medium on the other one. In the response function approach, a perturbation with momentum transfer Q and energy transfer ω is fed into the system (i.e., the nucleus) and the corresponding signal (i.e., the cross-section) is measured. A characteristic example is quasielastic scattering: the cross-section peaks near the free kinematical region with a typical broadening and strength given by the interaction and the momentum distribution.

This technique has recently been applied to the transverse and longitudinal (i.e., Coulomb) response functions in electron scattering, which now can be separately determined. As we have seen during the conference, the results have so far been as follows⁹:

- the transverse response function shows no anomaly. It has a universal "nuclear matter" shape and can be well described both via a correlation approach with $2p$ - $2h$ excitations or with relativistic mean field theory.

- the longitudinal response function poses problems. It depends both on A and Q . The area under the curve is a measure of the total charge. The puzzling feature is that 50% of the charge is missing (see Fig. 6).

FIGURE 6

Various possible explanations were discussed. One possibility is that np-pairs correlate so strongly that the corresponding excitations are pushed to higher excitation energies. A rough estimate indicates that this mechanism will only account for 1/3 or so of the effect. Another suggestion is that in a relativistic mean field description, the strength is renormalized, but this needs a clear physical explanation. A third suggestion is that nucleons swell by some 15-20% in the medium; this effect might enter, since the free nucleon form factor has been divided out in the response in Fig. 6, assuming tacitly that nucleons are inert. There are thus a number of suggestions, and it is as yet too early to make a choice. It is perfectly clear, however, that it would be very valuable to have additional information both at larger Q and at higher ω so as to pin down where the missing strength has gone. In the higher ω region, we should also obtain very interesting information on the behaviour of the Δ -isobar in the nucleon environment using the response function approach. A picture, in which the "truth" is that nuclei consist of inert nucleons, is thus at the limit of its abilities in the description of the experimental response functions. While we do not yet know whether the anomaly in the Coulomb sum rule is evidence for a modified nucleon structure or not in nuclei, it is certain that the Δ -isobar response carries us outside the purely nucleonic picture.

Closely connected to response functions are sum rules over nuclear excitations. In the last few years, the isovector Gamow-Teller $\sigma\tau^{\pm}$ has been found to be reduced to about 60% of the free nucleon sum rule. The usual interpretation of this effect is a renormalization of the axial strength in the medium due to the rescattering of virtual pions via the Δ ; this is analogous to the renormalization of the strength of an antenna in a dielectric medium. In his review, Arima¹⁰⁾ produced evidence that the isoscalar sum rule is quenched even more to about 30% of its value. Further, this effect is linked theoretically to the nuclear tensor correlations, i.e., to OPE. It seems likely that these two phenomena are connected, since both are linked to pion physics. This point should be further explored and elucidated.

Even inside the nucleon picture there is an additional, tacit assumption that the nucleus is a system of non-relativistic nucleons. Since spin is of relativistic origin, but is essential to any description, this is included together with the $\vec{l} \cdot \vec{s}$ coupling in the usual non-relativistic approach. In the last few years, the issue has been raised whether or not it is more effective to view the nuclear nucleons as obeying the Dirac equation with the small relativistic component of the wave function treated explicitly. This viewpoint was reviewed by Serot¹¹⁾. It is quite clear that the Dirac impulse approximation

works like a charm in the description of a variety of polarization phenomena in $\vec{p}$ -nucleus scattering down to fine details. This approximation clearly incorporates some crucial physical features normally neglected in the NN interaction. Are these features really relativistic? This is quite unclear to me: the practitioners have not made their case convincingly on this point. Let me recall the procedure. The NN amplitude is expressed in relativistic invariants, which is straightforward starting from phase shifts. One then averages over the target nucleons, which amounts to cutting out all but the vector and scalar couplings. This reduces the effect of the target nucleus to a scalar and a vector optical potential linear in density. At this point the impulse approximation is applied to the projectile. The final result now depends non-linearly on the density of the target due to the small component contribution. The problem in comparing to the standard impulse approximation appears on several levels. That approximation and its generalization to multiple scattering theory was developed long ago. At that time, the problem was not to describe subtle spin effects. In the Dirac constructions additional information on the NN scattering amplitude is implicitly included. For example, the optical potential constructed relativistically will be energy dependent in the non-relativistic version. In order to minimally preserve unitarity and orthogonality of wave functions, it is then necessary to introduce non-linear weight factors in matrix elements so as to restore consistency. This is not normally done. It is unreasonable to compare minimal Dirac relativity to a description that does not minimally respect unitarity. On another level, which is probably related, it has been pointed out after the conference by Thies¹², that a consistent normal treatment leads to a Lorenz-Lorentz effect in the $\vec{\lambda} \cdot \vec{s}$ term which produces non-relativistically the Dirac impulse approximation result. It is urgent and desirable to elucidate these questions. My personal opinion is that it would be rather surprising if relativity were to be essential on the level of the impulse approximation, the simplest approximation possible. At present, we have an effective recipe, but no real evidence, that relativity is an essential feature in nuclei.

The relativistic approach is also used in mean-field descriptions of nuclei. With phenomenological parameters, its results are not totally unrelated to reality. This approach uses a highly truncated version of meson exchange theory with only scalar and vector exchange: in particular the important π exchange is not treated this way. The consequence is large scalar and vector potentials, which cancel to a large degree. This result is somewhat mysterious insofar as all normal nuclear matter calculations rely heavily on the iterated tensor interaction from OPEP, which dominates the nuclear binding. How come that such a theory can treat OPEP perturbatively with huge phenomenological

background terms? These would normally be associated with iterated OPEP, but it is then unclear why it should be important to treat the effective iteration relativistically. It is clearly essential in using relativistic mean field theory to understand its relation to the usual many-body approach far more clearly than today.

It is important to note that a "smoking gun" for nuclear relativistic effects at low energy has recently been discovered. The reaction $\gamma d \rightarrow np$ at 0° has a strong kinematical suppression of the main E1 amplitude in the low energy region. The 30% anomaly in the cross-section, as compared to a non-relativistic description, is now firmly established^{13,14} (Fig. 7).

FIGURE 7

When Cambi et al.¹⁴ included relativistic effects in the current, agreement was restored; this result has since been confirmed by other groups. Although it should still be checked here as well that this is not generated by consistency alone, the effect seems genuinely relativistic. Thus, there is now one clear case of relativity relevant to low energy physics but otherwise "relativistic effects" correspond so far only to a "phenomenological truth".

Let us now turn to the area of nuclear physics in which the isobar degrees of freedom are explicitly excited. This is the area in which the "truth" is that nucleon phenomena are governed by the physics of π , N and Δ . The Δ -isobar is the outstanding feature in the intermediate energy πN interactions. We may first wonder how similar the Δ with spin-isospin $3/2-3/2$ is to the nucleon with spin-isospin $1/2-1/2$. Here an interesting number is given by the mass splittings between Δ^{++} , Δ^+ , Δ^0 and Δ^- . This splitting is extremely hard to measure

directly in particle physics, but it can be measured 30 times more precisely in nuclear physics. The trick is to use the deuteron with $T = 0$ and study the $\pi^\pm d$ total cross-section in the Δ -resonance region (Fig. 8). The difference in masses produces a charge symmetry breaking which shifts the resonant position slightly in the two cases: one can then directly observe the effect in a null experiment¹⁵. Compared to the n-p difference one deduces:

$$m(\Delta^0) - m(\Delta^+) = 1.36 \pm 0.06 \text{ MeV}$$

$$m(n) - m(p) = 1.29 \text{ MeV}$$

FIGURE 8

The remarkable result is therefore an identical mass splitting for the Δ and N masses with the same charges. In a naïve constituent quark model this is expected, since the Δ results as a spin-flip excitation of the u-d quarks in the nucleon. This similarity in the mass-splitting is a strong, although not rigorous, indication that the internal Δ -N structure is very similar. It has surprised me that no one of the advocates of nuclear quark physics has brought up this important evidence for a quark effect seen in a nucleus. Here is also a case in which the modification of a quark effect in the nuclear environment may be measurable: while the deuteron result most likely is little changed by the proximity of the nucleons, this may not be the case if the mass splitting is studied in a denser system like ^4He .

One of the most basic issues concerning the Δ -isobar is the extent to which it is modified in the presence of other nucleons. In fact, if we think of it as a resonating antenna, we all know that antennas resonate at a different frequency, or even not at all, when they are packed densely. The recent measurements at Bonn, Mainz and Saclay of the total γA cross-sections per nucleon¹⁶ in the Δ region (Fig. 9) are very significant in this context. The observation is that the resonance shape and strength is nearly universal from ^9Be to ^{238}U . There is no evidence for a shift of the Δ within the experimental precision, but the resonance is somewhat broadened as compared to the nucleon one. One expects this from Fermi motion and from absorption in the medium. There is no evidence for any anomalous attenuation of the resonance. These experiments are extremely important. First they show again qualitatively that nuclei consist to a very high degree of nucleons, even in the interior, to at least 90 or 95%. In addition, they show that the average Δ -nuclear interaction must be very similar to the average N-nuclear one, since the resonant shift is small. Finally, they demonstrate explicitly that the Δ -isobar is sufficiently

FIGURE 9

only a first qualitative approach. Such experiment should be complemented with (ee') inclusive data.

It is worthwhile to emphasize that this information is not easily obtained from π -nuclear scattering. The reason is not that photons interact more weakly than pions, the reason is that the Δ -excitation by photons is transverse, since it is an M1 transition. The transversality suppresses the elastic π -rescattering proportional to $(\vec{\epsilon} \times \vec{k}) \cdot \vec{q}'$ very strongly as compared to elastic pion rescattering proportional to $\vec{q} \cdot \vec{q}'$ since $\vec{q}'$ is preferentially in the forward direction. As a consequence the π -nuclear total cross-sections have large Δ -resonance shifts due to the coherent rescattering. This would be the case for the photon cross-section too, if the photon coupling to the Δ would be longitudinal as for a pseudoscalar. Apart from a small mass effect the forward photon-pion wave in the nuclear medium would be identical to the pion-induced one but for a scale factor! It is the transversality which makes the photon an ideal tool for exploring the Δ -isobar in nuclei.

The isobar excitation is a special case of photoproduction of pions in the nuclear environment, and it can be explored in many other details. Here I want to draw your attention to Mecking's brief comment¹⁷ on the status of the experimental $\gamma N \rightarrow \pi N$ and $\gamma N \rightarrow \pi\pi N$ amplitudes. These are not well determined at present. This is bound to become a great hindrance to future applications to nuclear physics. Even below the Δ -resonance the smaller M1 amplitudes (i.e., p-wave π production) are quite poorly known with uncertainties of up to 30%. This introduces a major uncertainty, for example, in the coherent (γ, π^0) production analysis on nuclei¹⁸. This is most unfortunate since such those experiments are among the best illustrations of chiral symmetry in nuclei. It is a necessary task to determine these amplitudes to an acceptable accuracy.

small so as to survive intact the proximity of other nucleons. All of these properties put severe constraints on theoretical approaches, whether based on π -N physics or on quark physics. Right now, it is easy to shift the Δ position inside of conventional descriptions by an amount larger than the experimental one. It is important that the experiments are improved in precision and statistics to a point at which the properties of individual nuclei show up: the present experiments are

These features of the Δ in nuclear matter are akin to the description of nucleon interactions in nuclear matter in terms of an average potential. We are familiar, from the nucleon problem, with the importance of understanding the NN interaction for a correct understanding of the nucleon in the nuclear environment. Key ingredients are the properties of the deuteron, the bound NN state, as well as the nearly bound singlet state. In this perspective the ΔN and $\Delta\Delta$ interactions are essential for an understanding of Δ in nuclear matter. The question of bound ΔN and $\Delta\Delta$ is of particular interest for the same reason as the deuteron is important. The detailed nature of the ΔN interaction is at present imperfectly known although OPEP plays an important rôle. The bound states will be non-strange dibaryon systems. These will inevitably be broad, reflecting the width due to Δ -decay. There is seemingly evidence for two such ΔN dibaryons in the region of the ΔN threshold. The NN 1D_2 channel has a quite clear resonance corresponding to a 5S_2 (ΔN) state with $L = 0$ at about 270 MeV above the NN threshold. In addition, there is a less obvious, but still rather clear resonance in the 3F_3 NN channel corresponding to a 5P_3 (ΔN) state with $L = 1$ at about 370 MeV above threshold. Both of these states have aligned ΔN spins, so that they can make maximal use of the OPEP attraction via iterated Δ excitation on one or the other of the two nucleons (see Fig. 10).

FIGURE 10

On the other hand no $\Delta\Delta$ states have been observed so far. With the concrete experimental starting point of the observed $N\Delta$ resonances, it is now possible to approach the $N\Delta$ problem more in depth. This can be done both from a two-body point of view as a coupled $N\Delta$ system suitably modified to include the Δ -width, or from a three-body Faddeev type of approach to the resonant πNN system as was reviewed by Tjon¹⁹. These descriptions are interesting not only

in their own right, but as well as for understanding the Δ interaction in nuclei. In addition, they should clarify the old problem of isobar components in the deuteron wave function as well as in the quiescent nucleus in its ground state. For this we badly need much better information on non-strange dibaryons with high quality data. Likely sources for such information are polarization experiments in well-specified channels in NN scattering, NN π -production, π d-absorption as well as $ed \rightarrow e'X$ data at intermediate momenta.

From the present experimental evidence, it stands out quite clearly that the Δ -isobar is a "true" nuclear component in the sense that it survives largely unchanged in a nuclear environment. It is not yet clear to what extent the Δ -isobar can be considered a separate entity, say, in a nuclear ground state.

Non-nucleonic degrees of freedom manifest themselves in a number of weak and electromagnetic phenomena associated with nuclei in the ground state or coupling to low lying excitations. This is the classical area of meson-exchange currents. Such effects are now very well established in several cases for the lightest nuclei, for which the wave functions are not a source of uncertainty in the analysis. The effects are particularly large in the isovector magnetic form factors (order M^{-1}), while isoscalar effects are less well established (order M^{-2}). This is traditionally illustrated by the isovector 3S_1 transition in the deuteron backward electrodisintegration, which now is explored to $Q^2 \approx 30 \text{ fm}^{-2}$, i.e., with a spatial resolution of about $\frac{1}{2} \text{ fm}$ (Fig. 11). One of the theoretical problems in describing meson-exchange currents is that one calculates various diagrammatic contributions from π -exchange, ρ -exchange etc.. Where should one stop? Does the procedure converge? A very valuable theoretical advance due to Arenhövel-Leidemann and to Riska was reported by Delorme²⁰. They introduce consistently a minimal electromagnetic coupling in a realistic NN potential which describes the NN phase shifts well. This avoids entirely the expansion problem although the procedure is not entirely without ambiguities. The resulting description of the deuteron electrodisintegration

FIGURE 11

data is impressive and agrees with careful diagrammatic results²¹. The understanding of this part of the exchange current is further elucidated by the beautiful new data on the ^3H charge and magnetic form factors reported by Platchkov²². In particular, the magnetic form factor gives very strong evidence for contributions by the pion Kroll-Ruderman or pair term to the isovector form factor for both moderate and large Q^2 . Meson exchange currents, and in particular those associated with OPE, are an important "truth" of electromagnetic transitions and of weak interactions as well.

In the analysis of experiments at large Q^2 it is important practically to know the electric form factor of individual nucleons. It makes quite some difference whether the nucleons couple with the Dirac form factor $F_1(Q^2)$ or with the Sachs form factor $G_E(Q^2)$. Although the issue is not fully settled, strong arguments have been given for F_1 in preference to G_E ²⁰. One should note that the Sachs form factor is arbitrary in the sense that it contains $F_2(Q^2)$ which corresponds to a part of the current, which is conserved independently of the remainder: current conservation imposes no restriction.

The increased insight into the form factors of the $A = 3$ system coming from the new ^3H data has revealed an anomaly. The isoscalar and isovector form factors can now be separated. While the isovector charge form factor behaves as expected, the isoscalar one exhibits a very substantial discrepancy²² (Fig. 12) in the region $Q \approx 2-3 \text{ fm}^{-1}$, i.e., near the maximum of the form factor. The anomaly occurs at rather low Q and must be associated with spatial distances of 1 to 1.5 fm. It is thus unlikely to be due to non-nucleonic effects; most likely it is due to a novel and overlooked feature of the $A = 3$ wave function at intermediate range.

FIGURE 12

Up to this point the "truth" about nuclei has appeared in terms of nucleons and isobars interacting via mesons. On the whole it is a quite successful truth pinned down by many experiments. Quarks and gluons are not much called for on this level. On the other hand, there is ample evidence from particle physics that QCD with quarks and gluons works very well concretely: for nucleons it has even been possible to map the distribution of the different quarks explicitly. It is a pretty picture and we firmly believe that also in the nucleus quarks and gluons are the basic building blocks. The central question in this perspective is: how do they manifest themselves and what criteria for acceptable evidence should we use? What are the "smoking gun" experiments for nuclear quarks? or, as the French would say, how do we catch a nuclear quark "en flagrant délit"? We must obviously aim for "clean" situations with alternative explanations unlikely or, better, suppressed. Unless other explanations can be ruled out beyond arguments, we do not want to have 10% effects as evidence. Wilkinson has well defined the problem in the following terms²³: "We must not be tempted into mistaking a demonstration of consistency between nuclear behaviour and expectation based on an explicit involvement of quarks for a proof of that involvement"... "We gain nothing", "...", "unless those descriptions bring us an understanding of nuclear structure and transitions enhanced above that based on the Δ and ρ as elementary particles".

The EMC effect provides the most specific example of a quark effect in nuclei. Inside of a quark description the deep inelastic muon scattering demonstrates clearly that the quark distribution per nucleon in a nucleus differs from that of a free nucleon. The evidence for this is irrefutable and everybody agrees with this statement. The part of the issue which is not settled is whether this changed distribution is produced by $q\bar{q}$ pairs incarnated as pions, or is produced by the nucleon binding or whether it is a genuine novel manifestation on the quark level linked to incipient deconfinement like the effect produced by an increased bag radius²⁴. It is important to restrict such possibilities as much as we can by bringing all the new information we can find. Two novel points were injected in the discussion during the conference: first, Thomas²⁵ drew attention to the importance of nucleon binding in the EMC and advocated that this aspect be further explored. Second, there was a considerable discussion on the experimental restrictions on nucleon swelling inside nuclei. In particular, (ee') nuclear y -scaling at large Q^2 has now been studied out for the first time and the preliminary analysis of ^{27}Al was

reported^{26,28}. The data seemingly speak against a nucleon swelling by more than $\approx 5\%$, since the assumption of a normal nucleon size works very well (Fig. 13). However, the detailed analysis was questioned so any firm conclusion is premature; we eagerly await the final analysis. Electron scattering specialists consider 5% swelling a generous upper limit, but this strong restriction comes from light elements. Finally, magnetic moments in nuclei scale with the bag radius and are therefore sensitive to nucleon swelling in nuclei. While the detailed relation is less transparent, specialists like Arima insist strongly that modifications of magnetic moments on the 5-10% level will cause havoc. All of these point to a small nucleon swelling, while the EMC explanation needs about 15% or even more. The situation is further confused

FIGURE 13

by the analysis of Mulders of quasielastic electron scattering on ^{12}C at $Q \approx 550 \text{ MeV}/c$. At this low Q there seems to be evidence for an increased nucleon size.

There is no answer to the question of nucleon swelling at present. The crucial point is however that the issue now is approached in a variety of ways independent of the EMC effect. In the future we expect therefore well-argued limits established by different means restricting the theoretical explanations of the EMC effect.

On the conceptual level an interesting consequence of a quark model for nucleon form factors has been brought up by Desplanques and Drechsel²⁰. It is well known that a system with a radius or a form factor necessarily has excited states in quantum mechanics. As a consequence, the use of form factors with inert nucleons becomes a questionable procedure, when couplings are iterated.

A particular case is the so-called pair graph or Kroll-Ruderman terms for $\gamma N \rightarrow N\pi$ in meson-exchange interactions (Fig. 14). The momentum transfers in the vertices can be quite large and lead to very strong damping of this term if the nucleons are taken to be inert. The observation is now that if one uses form factors from the quark bag models, damping is indeed very strong, but if the excited states of the quark bag are included, this restores the result of a point nucleon, at least for simple models. An analogous result is known from interactions: the πNN form factor in OPE exchange in the deuteron appears effectively nearly point-like in the tensor interaction, when the exchange term from quark antisymmetrization is included²⁷. While these results are theoretical they may indicate a mechanism used by the quarks to "hide" inside nuclei.

FIGURE 14

The issue of how we should go about establishing evidence for quarks in nuclei was addressed by an expert panel, but with inconclusive results. I believe it is important to realize that the quark hunt may lead us onto new ground whether quarks are "seen" or not. First, we learned from Bosted²⁸, that SLAC now measures the deuteron form factors out to $Q^2 \approx 120 \text{ fm}^{-2}$. This means that the deuteron now is probed to distances of about 0.2 fm, which is a factor two better than presently. At this level, the experiment clearly is sensitive to detailed features well on the level of the structure in any quark description. Most likely, the deuteron electrodisintegration and the $A = 3$ form factor at these Q^2 are even better systems to study such effects, and we can now expect them. Second, the system of hypernuclei and nuclear physics with strange particles should provide a happy hunting ground. Since Λ and Σ hypernuclei can be regarded as nuclear systems with controlled and tagged impurities, they are a rich source of physics in their own right. In particular, the strange quark can be directly "observed". Yamazaki²⁹ brought up the interesting possibility that the strange quark may be less confined than normally, since the Pauli principle is inoperative for it. This may be amenable to observation. It is not clear whether an electron or a hadron accelerator gives the most effective approach practically.

It is important to keep in mind that hypernuclear systems with $|S| > 1$ are most interesting objects. For example, the $\Lambda\Lambda$ system in a flavour singlet quark configuration may give a dibaryon of low mass as suggested by Jaffe. For the same reason we should enquire also whether $\Lambda\Lambda$ hypernuclei with larger A may not show evidence for similar configurations, quite apart from the rich information on $\Lambda\Lambda$ physics they would provide. Experimentally such studies are within reach from K^-K^+ charge exchange reaction from stopped E^- reactions as well as from strange processes at antiproton storage rings like LEAR. Nuclei with $|S| > 2$ may exhibit even more binding and provide missing dark matter in the Universe as suggested by Witten. This becomes quite speculative however.

A third approach to quark physics is that pursued using relativistic heavy ions. The idea is to squeeze so much energy density into an interaction volume that a phase transition to a quark-gluon plasma develops. There are good theoretical reasons to believe that such an effect should occur. This road aims for a spectacular effect, although surrounded by much background. Its characteristic features are

- a typical signal (if seen at all)
- but, a complicated many-body situation.

The last point is important, since it implies that the detailed structure of the interaction will be difficult to explore even if the signal is observed. The consequence of this is that low energy exploration of quark physics will be a very important complement to the relativistic approach [once more a caveat: a signal must be found]. The characteristic feature of electron machines, in particular, is their ability to isolate exact features of the system under study in an unequivocal manner. For this reason the heavy ion approach and the electron approach are not rival ones but complementary. It is by a common attack by these means that we hope to establish QCD as a nuclear "truth" as well.

In conclusion, as we examine the physics of nuclei on various levels we find many "truthful" descriptions. These are not contradictory to each other; each of them is invaluable for our understanding of nuclei inside its region of validity. It is characteristic that each of the approaches uses a wealth of knowledge, for instance on NN , on πN or Δ interactions, on the elementary level which is quantitatively incorporated in the description of the appropriate "truth". The many new developments presented at this conference bear ample witness to the many "truths" in nuclear physics.

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