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VI.e. Comments on the Mesonic Effects in Nuclei

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It is a great pity that Professor Migdal could not come to give his talk on the interesting results he has obtained on mesonic effects in nuclei. A brief look at preprints of his work reveals an interesting contact to the approaches of Professor Miyazawa and Professor Brown. I was asked to replace him and give a similar talk on the subject. This is, however, quite difficult for me, since I am utterly unprepared and furthermore I have no recently finished work to report. So I shall instead comment on different approaches heard in this Conference and perhaps clarify some of the unclear points.

Unlike the game of core polarizations etc, the matter of mesonic degrees of freedom has practically no systematic method to rely upon. For this reason, lots of wrong papers appear in the literature, quite often creating a considerable amount of confusion. Calling them mesonic connections, people tend to keep adding graphs with little or no justification. The role of N* in this matter is quite obscure and creates difficulties in some approaches.

Let me illustrate some of these points with the three-nucleon system ^{3}H and ^{3}He discussed by Gerry Brown. According to one version of mesonic correction, namely the idea of exchange currents which became quite popular recently, the pionic correction to the magnetic moment and to the Gamow-Teller (G-T) matrix element arises from the two-body effective operator represented by Fig. 1, where the wiggly line corresponds to the electromagnetic or weak axial current and the blob represents all the mess present in the off-shell pion production amplitude. One of the modern developments in treating this is just that this can be now reliably calculated, thanks to the recent development of current algebra and various different methods give similar answers, so one could consider this as model-independent. Once we are assured that we are calculating the blob, it would not be justified to add a term like Fig. 2, in which V is an NN potential, since the one-pion-exchange part of the graph is understood to be already taken care of by the blob in Fig. 1. Consequently the recent calculation of Gerstenberger and Nogami where Fig. 2 is added to the Chemtob-Rho result cannot be correct.

It appears, however, that a "satisfactory" treatment of the blob in Fig. 1 seems to go wrong somewhere, since whereas the magnetic moments come out rather well (see Kim *et al.*, contribution to this session), the correction to the G–T matrix element overshoots the required

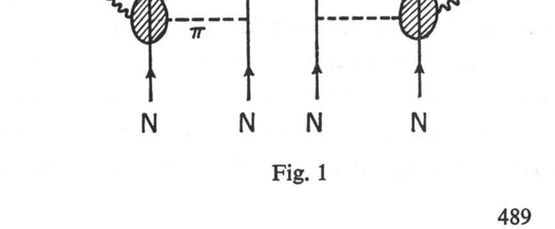

Fig. 1

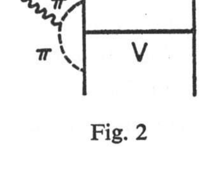

Fig. 2

magnitude by a factor of two or three. The culprit here seems to be the S–D interference term of the current containing $N_{3,3}$ (or Δ)—the operator with the blob in Fig. 1 replaced by $\pi N \to N_{33} \to N$ current—which dominates the whole thing in the G-T matrix element. Ichimura, Hyuga and Brown (IHB) find an interesting way out of this difficulty by putting $N_{3,3}$ into the nuclear wave function (an idea originally suggested by Green and Schucan). What happens is then a delicate cancellation among the terms containing $N_{3,3}$, with the resulting $N_{3,3}$ contribution effectively suppressed. Both the magnetic moments and the G–T matrix element come out rather nicely through this cancellation mechanism.

I am sure that this model of Ichimura *et al.* will teach us a lot on how N_{33}'s come into the mesonic nuclear society. But this simple model may not be realistic enough for the problem, as one can easily find loop-holes in the treatment. Although the IHB model explains in a nice way the suppression of $N_{3,3}$ contribution, it, however, does not resolve the difficulty. After all, the situation is like the effective charge. It is a well-known practice in nuclear physics that whatever is not put into the wave function is to be put into the operator, the matrix element of which is related to the "effective charge". So one would expect the former method to be all right in principle. What goes wrong might then be found in the way that the $N_{3,3}$ is introduced or more generally in the way that the meson exchange is treated.

One way that K. Kubodera and I think can resolve this is a generalization of Cutkosky's Heitler-London picture (originally used for deuteron) to the three-nucleon system. Let me briefly describe how the deuteron problem is treated. The deuteron wave function is taken to be the conventional non-relativistic one with the S and D state admixtures; however the new ingredient is that the triplet spin function which in the usual description contains no internal degrees of freedom of the two nucleons is replaced by the generalized two-nucleon function

$$\Phi_m = \phi_m + \sum_{m'k} C_{mm'}(k)\phi_{m'}(k) \cdots \tag{1}$$

Here m is the third component of the spin, ϕ_m the basic HL state, $\phi_m(k)$ the excited HL state with a meson of momentum k, etc. The function Φ_m should properly be normalized when calculating observable quantities. What makes (1) different from, say, the equation that Gerry Brown wrote down in his talk is that ϕ_m is a true eigenstate of the field theoretic Hamiltonian when the two nucleons are far apart, so that when the two meson clouds begin to overlap, the electromagnetic current or weak current can receive contributions from virtual excitations of nucleon resonances. Thus there would be a contribution from the $N_{3,3}$ even when the excited HL states are ignored. Note that only when meson exchanges are ignored in the matrix element of the electromagnetic current taken between the basic HL states, would the resulting magnetic moment be just that given by $\mu_d = \mu_s - \frac{3}{2}(\mu_s - \frac{1}{2})P_D$ (P_D is the D-state probability).

We propose that this method be applied to the tri-nucleon system by considering a $T = 1$ quasi-deuteron system. Because of additional complexities arising for the isovector current, the analysis is expected to be somewhat more complicated. But it appears feasible.

The advantage in this method is that there is no need of renormalization, since the matrix elements are given in term of measured quantities. There is furthermore no serious obstacle to the validity of the procedure as there is in the quark model of Ichimura *et al.* The normalization is properly taken care of into the effective two-body operator, not to the wave function in contrast to the approach of Ichimura *et al.* There is, however, a price to pay. This can become rather costly in particular, in $T = 1$ case. Since ϕ_m and $\phi_m(k)$ (and higher HL states) are not orthogonal, algebra can become rather complicated. A generalization beyond the static model is at present non-existent. The π–π interaction cannot be taken into account in the formulation without losing the power of the method. At the very least, this method will nevertheless indicate how one should normalize the exchange current when nucleon resonances are involved.

Let me now comment on one aspect which seems to be misunderstood by some people in this conference. That is the mesonic correction to $\langle \tau_3 \boldsymbol{\sigma} \rangle$ in heavier nuclei. It is argued that in β-decay, g_A is small, so that one would expect the quantity $\langle \tau_3 \boldsymbol{\sigma} \rangle$ to be reliably obtained from *ft*-values. I would say that from the theoretical point of view, this may not be too grossly wrong in light nuclei, but it is highly questionable in heavier nuclei. From Wilkinson's analysis, one knows that there is about 7% quenching in g_A for light nuclei. On the other hand, the sum rule (a kind of Adler-Weisberger sum rule for nculei) written down by M. Ericson suggeste that the quenching should increase as nuclear mass increases. Thus in heavy nuclei, the deviation from the free value $g_A = 1,23$ could be substantial. There is a room for improvement in Ericson's sum rule, but it is a warning to the core-polarization enthusiasts that it is not a good policy to calculate only a few effects and forget the rest.

It is not going to be in magnetic moments alone that we will learn in a clean way how the mesons function in nuclei. There are so many conflicting effects in such quantities that a non-ambiguous conclusion will never be drawn. For this, one has to go either to a more violent perturbation or to exotic reactions where the mesonic effects dominate. Up to now, no such experiments are known to be feasible, but I don't see anything wrong for a theorist to indulge in some. Let me first consider the case of high momentum transfer. Moniz, Chemtob and I, inspired by the work of Blankenbecler and Gunion, are studying the magnetic form factor of deuteron (and eventually of ^{3}He) at very high momentum transfer. We conjecture that some form of mesonic degrees of freedom will dominate and in particular, it will involve the vector mesons. Taking the vector dominance picture, the isoscalar photon can be visualised as an ω meson which rescatters or gets converted into another vector meson by nucleons in the deuteron. The large momentum transfered will in this description be shared by the two nucleons; therefore the form factor is expected to fall off less rapidly than the single-body form factor. We believe that such effects are more important than the excitation of N_{33}'s in the collision.

When the neutrino process discussed by Walecka does turn out to confirm the existence of second-class currents, then the mirror β-decay asymmetry discussed by Wilkinson will become a nice source of mesonic message. According to Kubodera, Delorme and myself, the asymmetry due to the second-class current should in general read as

$$\delta = -4\frac{\alpha}{g_A}J + \frac{2}{3g_A}(\alpha L - \zeta)(W_0^+ + W_0^-) \tag{2}$$

where J and L are matrix elements of a two-body mesonic current, α contains $\omega\pi$-coupling to the second-class current and ζ is the nucleon-coupling to the current. The neutrino experiment will determine ζ and hence α will be determined *via* the residual mirror asymmetry

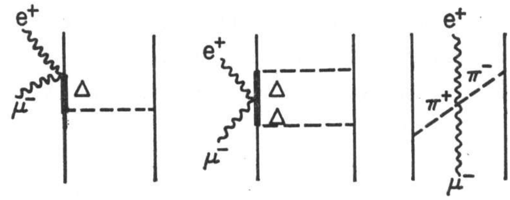

Fig. 3

unaccounted for by nuclear effects. As one can see from eq. (2) a large energy independence will be a direct indication of mesonic contributions.

If one wants to study selectively the effect of $N_{3,3}$ (or Δ) in nuclei, one should choose a process where no other contribution is possible. Although it involves other question marks, I can think of one; namely the process

$$\mu^- + {}^{A}Z \to e^+ + {}^{A}(Z+2)\ . \tag{3}$$

It requires an isotensor current and the lepton scheme of Konopinski and Mahmand. Shuster and I have taken up this process and uncovered some interesting things about it. The process can go only through a two-body interaction, the basic mechanism of which can be represented by Fig. 3. It turns out that if the isotensor vector current is also conserved, then the last diagram vanishes. Thus the $N_{3,3}$ (Δ) plays a crucial role in making the process (3) go. I should hasten to caution that there is no evidence yet of the existence of the isotensor current nor any experiment supporting the K–M scheme. So the relevance of this process to our objective is not immediate. However, there are experiments planned to settle these important questions and the results may not be too far to come.

Discussion

Y. E. KIM (Purdue Univ.): As I understand it, the Cutkosky Model is extremely difficult to use in practice. Do you anticipate any results coming out soon from the model?

RHO: I think we can understand how to do it for the triton. It is true that it is rather difficult, but there is a definite prescription of doing it.

L. ZAMICK (Rutgers Univ.): The Yamazaki prescription $g_l = 1 \to g_l = 1.1$ treats mesonic effects as a one-body operator. Is there any phenomenological evidence in nuclei where the mesonic exchange moment acts as a two-body operator?

J. -I. FUJITA (Tokyo Univ. of Education): The exchange moment has a natural expression as a two-body operator. So there is no reason to use one-body operator except that it is very convenient.

T. YAMAZAKI (Univ. of Tokyo): In our empirical analysis we have assumed a one-body type bare operator. This is, of course, for simplicity, but an assumption of state-independent δg_s and δg_l factors may probably be good for nucleons moving around the Fermi surface. However, deeply bound core particles might have significantly different constant δg_s, as Prof. Miyazawa has shown. So far, in evaluation of the first-order configuration-mixing correction, the free nucleon g_s factor is assumed. I wonder how much difference is expected theoretically.