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To cite this version:
Y. Avishai. FORMAL THEORY OF WEAK Nd SCATTERING. Journal de Physique Colloques, 1984, 45 (C3), pp.C3-71-C3-73. <10.1051/jphyscol:1984313>. <jpa-00224027>

HAL Id: jpa-00224027
https://hal.archives-ouvertes.fr/jpa-00224027
Submitted on 1 Jan 1984

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FORMAL THEORY OF WEAK Nn SCATTERING

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Résumé - Nous présentons une théorie de la diffusion pour un système de trois
nucléons soumis à une interaction NN qui comprend une partie forte ainsi
qu’une partie faible.

Abstract - We develop a theory for three nucleon scattering in which the NN
interaction contains strong and weak parts.

1 - INTRODUCTION

There has been a great excitement following the neutron spin rotation experiments at
ILL \(^1\)). The ensuing theoretical works \(^2\)) were focused on the possibility of enhance­
ments due to nuclear structure effects (most notably neutron resonances). These ef­
ferts, successful as they are, cannot lead to a clear and transparent relation be­
tween the calculated results and the fundamental weak NN interaction. Indeed, neutron
resonance is a complex many particle phenomena and this turns the interpretation
rather obscur. Thus, it is now evident that neutron spin rotation experiments should
be performed on the lightest nuclei, for which theoretical interpretation is feasi­
ble in terms of the basic weak and strong NN interactions.

A natural starting point would of course be n-p scattering. However, it is clear that
hydrogen target is not appropriate for the spin rotation experiment (among others,
protons have large cross-section for the capture of cold neutrons). Furthermore, the
strong isospin dependence of the weak NN force (e.g, isovector terms with \(T_1^2 \neq T_2^2\)) sug­
gested that n-n interaction should also be studied, together with the n-p interaction.

Consequently, it appears that an experiments like n-d and p-d scattering are indispen­
sible in the study of the strangeness conserving non-leptonic part of the weak inter­
action Hamiltonian which is responsible for parity non conservation (PNC) in nuclei.
On the theoretical part, one should have a theory of the three nucleon system in
which the NN interaction contains both strong and weak parts. At present, such
theories are based on non-relativistic potential scattering approach and hence they
are limited to low and medium energy scattering. In the present contribution, a prac­
tical scheme for calculating weak interaction observables in the three nucleon sys­
tem will be briefly reviewed (A more detailed account has recently been published
by the author \(^3\)). Earlier works in this direction include those of Desplanques et
al \(^4\)) and of Kloet et al \(^5\)).

In section 2 we will discuss the two nucleon problem while the three nucleon system
is treated in section 3.

2 - THE TWO NUCLEON SYSTEM

2A - The Weak and Strong NN Interaction. At present, one cannot derive the weak
interaction between hadrons from basic principles. It is suggested by several au­
thors \(^5\) that at energy less than 300 MeV the form of the weak NN potential arises
from the exchange of mesons. This picture is convenient for the assignment of range
and spin-isospin structure of the weak NN force. It should be stated that this
approach is phenomenological. The physics is still hidden in the weak NN (M=\pi, \rho, \omega) vertex and is taken care of by parametrizing the form factors and weak coupling constants \( g_{\text{NNM}} \). (In fact this is also the situation in the strong interaction (based on meson exchange) regime with strong form factors and coupling constants \( g_{\text{NNM}} \). This point will certainly undergo a drastic change in view of the bag models). The non-relativistic form of the weak NN potential derived from the meson exchange model contains isoscalar terms like e.g \( C_{\pi} T_1, T_0 \left( \vec{q}_{1} \cdot \vec{q}_{2} \right) \left( \vec{p}_{1}, \vec{p}_{2}, \vec{v}(r) \right) \) and isovector terms like e.g \( C_{\rho} T_1, T_0 \left( \vec{q}_{1} \cdot \vec{q}_{2} \right) \left( \vec{p}_{1}, \vec{p}_{2}, \vec{v}(r) \right) \). Thus, the weak NN potential \( \mathcal{V}_W(\vec{r}_1, \vec{r}_2) \) assumes here a definite analytic form (though rather involved). In momentum space, the interaction \( \mathcal{V}_W(\vec{r}_1, \vec{r}_2) \) can be decomposed into its partial wave components and singlet triplet transitions are possible. It should be stressed here that \( \mathcal{V}_W \) is not separable and cannot be approximated by a short sum of separable terms.

For the strong NN interaction \( \mathcal{V}_S \), we adopt here a separable form \( \mathcal{V}_S = \lambda |\gamma_S > \gamma_S | \). In principle, a small non-separable term can be added but that option will not be discussed here.

2B - Formal Solution of the Two Body Problem. Consider then a two nucleon system with the interaction \( \mathcal{V} = \mathcal{V}_S + \mathcal{V}_W \) discussed above. Our intention at this point is to obtain expressions for the quantities which serve as input to the three body equations. These include the strong form factor \( |\gamma_S > \) (assumed to be given) which controls the strong dissociation of two nucleon isobars (fig. 1a), the weak form factor \( |\gamma_W > = \mathcal{V}_W(\vec{r}_1, \vec{r}_2) \) responsible for weak decay of two nucleon isobars (fig. 1b; \( \mathcal{V}_W(\vec{r}_1, \vec{r}_2) \) is the two nucleon propagator) and the two nucleon scattering amplitude \( f \) resulting from \( \mathcal{V} = \mathcal{V}_S + \mathcal{V}_W \). To first order in \( \mathcal{V} \) one has \( f = \mathcal{V}_W(\vec{r}_1, \vec{r}_2) \left( |\gamma_S > \gamma_S | \right) \delta \left( |\gamma_W > \gamma_W | \right) \) (fig. 1c) where \( \delta = (\lambda - |\gamma_S > \gamma_S |)^{-1} \) is the (strong) isobar propagator. Thus, \( f \) contains small non separable term together with small and large separable terms. The expression for \( f \) thus obtained seems rather formal but in fact it can easily be used in practice once the non-relativistic form of the interaction is given.

3 - THE THREE BODY EQUATIONS

We now have a three nucleon system in which each two nucleon pair interacts both strongly and weakly as described in section 2. The form factors responsible for strong and weak dissociation of two nucleon isobars are calculable together with the two nucleon scattering amplitude. Since this amplitude contains separable plus very small non-separable term the most appropriate three body formalism is the one developed by AGS. However, since the two body t matrix contains also small separable terms, (which should be taken in first order) the AGS algorithm must be slightly modified and combined with distorted wave formalism. Let us first denote by \( \alpha, \beta, \gamma \ldots \) the usual pair spectator asymptotic channels and write the three body amplitude \( X_{\alpha \beta} = X_{\alpha \beta}^S + X_{\alpha \beta}^W \) as a sum of strong and weak parts. Assume that we have solved the three
body equations in which the weak interaction is absent. In the separable approxima-
tion we then get the strong amplitudes $X_{\alpha \beta}^S$ from the set of integral equations

$$X_{\alpha \beta}^S = Z_{\alpha \beta}^S + \tau_\gamma Z_{\gamma \alpha}^S \gamma_{\alpha \beta}^S,$$

where (with $G_o$ being the three nucleon free propagator) the

strong driving terms $Z_{\alpha \beta}^S = \gamma_{\alpha}^S |G_o| \gamma_{\beta}^S$ are depicted in fig. 2a while $\tau_\gamma$ is the pair

spectator (strong) propagator. Using matrix notation $X^S = Z^S + \tau_\gamma x^S$ we now construct

the strong Möller operators $\Omega = I + X^S \tau$, $\Omega^S = I + \tau x^S$. It is then shown 3) that the weak amplitudes are given by

$$X_{\alpha \beta}^W = \gamma_{\alpha}^W |G_o| \gamma_{\beta}^W,$$

$$Z_{\alpha \beta}^W = \gamma_{\alpha}^S |G_o| \gamma_{\beta}^S.$$

The first two terms of $Z_{\alpha \beta}^W$ (fig. 2b) result from weak dissociation of two nucleon

isobars. If this isobar is the physical deuteron, then these terms reflect the oc-
currence of P wave components in the deuteron wave-function. The third term in

$Z_{\alpha \beta}^W$ (fig. 2c) results from the non-separability of $V^W$ and represents weak NN scat-

tering at the intermediate states. In case the only two nucleon isobar is the physi-
cal deuteron it is this term which distinguishes nd from pd scattering. Hence, can-
cellation of this term with the other two of fig. 2b is improbable.

Finally, we notice that at zero energy (as in the neutron spin rotation experiment)

the strong amplitude can be approximated by scattering length , and hence the strong Möller operators are easily calculated (adopting on-shell approximation). Hence,

the evaluation of the spin rotation angle is feasible. The formalism described above is applicable of course also at higher energies in the calculation of the pertinent

asymmetries.

References.