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PARITY NON-CONSERVING EFFECTS IN NEUTRON-NUCLEUS SCATTERING

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suppression is not so strong as what one would naively expect by assuming that

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ABSTRACT

The present lecture reviews the motivations which led to study the contribution of the neutron-nucleus component to parity-non-conserving effects observed in medium-heavy nuclei and considers its present status. It is shown that it cannot account for those experimental data. The other interpretation of these effects, which cannot lead to precise statements, is schematically described.

1. INTRODUCTION

Parity-non-conservation (pnc) is a phenomenon whose origin is still unclear and which, in our opinion, may have to do with the nature of charges themselves, a topic which underlies a large part of the studies on neutrinos presented at this meeting. Indeed, the neutrino might be a Dirac particle at one extreme or a Majorana one at an other extreme. Here, we will consider parity violation from a much less fundamental viewpoint. While its study in nuclear physics was once considered as a tool to get information on weak interactions /1/, it subsequently appeared that this goal could not be reached due to the difficulty to control strong interaction effects at the quark level or at the nucleon level. Thus, the original goal has changed and we may now hope that this study of parity-non-conservation in nuclear forces will provide further information on how it arises at the quark level.

At the nucleon level, it is certainly in neutron-nucleus scattering at thermal energies that these strong interaction effects have shown up the most strinkingly. While the typical size of pnc effects in nuclear physics at low energy is expected to be of the order of 10^{-7}, the first positive effect to be measured turned out to be of the order of 10^{-4} (Abov et al /2/). Later on, an even larger effect, of the order of 10^{-1}, was measured in ^{139}La /3/. This is the largest pnc effect ever measured in a process which is not typically a weak interaction one.

While large enhancements were predicted long ago in some cases /4-8/, not always explicitly however, it is only recently, after some debate on the very

component to an infinity of different discrete states rules out such an explanaorigin of those large effects that a somewhat complete understanding has emerged [9-10]. Two interpretations, which share the idea that the enhancement of the effect is due to the proximity of the threshold of some resonance, were in competition. In one case, parity-non-conservation is supposed to take place at the level of the neutron-nucleus component of the scattering state [8,11-19]. The interest of this approach resides in the fact that it directly involves the strength of the neutron-nucleus weak force, making possible some relationship with the pnc NN forces on which, therefore, some information may be obtained. It offers the advantage of a maximum overlap for the parity admixture. In the other case [4-7,9-10], parity non conservation is supposed to occur at the level of the discrete states admixed to the nucleon-nucleus component by the strong interaction. Due to the unknown structure of these states, the relationship to parity-non-conservation in NN forces is only statistical and, therefore, this approach cannot provide precise information. Contrary to the other approach, the parity admixture of these states is expected to be suppressed. However, when close to a resonance, the probability to find the total scattering state in one of these discrete states is, within the nuclear volume where the weak interaction is operating, much larger than for the neutron-nucleus component. This can compensate for the suppression mentioned above.

More interested by getting reliable information on parity-non-conservation in NN forces, we were naturally inclined to look at the first interpretation of those effects measured in neutron-nucleus scattering (see lecture by Krupchitski at this meeting). In this lecture, we essentially present the results of that research, largely made with the collaboration of S. Noguera [19]. The main philosophy of this work is the following. If it makes sense to describe pnc effects in neutron-nucleus scattering from a neutron-nucleus force, then we should do it for several nuclei together, and not only for one as it turned out possible assuming favorable circumstances. In this order, we made improvements over previous works and elaborate some material relative to the description of the scattering states (strong interactions), which, we believe, may be useful for other purposes.

In this lecture, we will first review what is known on the nucleon-nucleus parity-non-conserving force. This is partly done to show that our information on the neutron part is rather limited and, by comparing to the proton part which seems to be well determined, to provide some expectation for its magnitude. The two next sections are devoted to the scattering states and are only dealing with the strong interaction. In the first of them, we consider the problem in its full generality, while in the second one we describe a few soluble models and compare their predictions to experiment. Only technical details necessary to the understanding of the text will be given; more details may be found in ref.(19). The fifth part is dealing with the pnc observables in elastic neutron-nucleus scattering and their relation to the pnc neutron-nucleus amplitude. In section VI, we give successively results for the ^{117}Sn nucleus, where we discuss the sensitivity to different approximations, and for a series of nuclei (^{81}Br, ^{111}Cd, ^{117}Sn, ^{139}La). Last section is devoted to the other interpretation and some comparison with the present one.

II. THE PARITY-NON-CONSERVING NUCLEON-NUCLEUS FORCE

In the simplest form, the pnc nucleon-nucleus force may be parametrized as /20/:

$$H^{p,n}_{p.n.c.} = \frac{\pi}{M^3} \; \chi^{p,n}_N \{\vec{\sigma}.\vec{p},\rho(r)\} \; , \tag{1}$$

where ρ (r) represents the nuclear density. The constants, χ^p_N and χ^n_N, respectively represent the strengths of the proton and neutron parts of the nucleon-nucleus pnc force. As isospin is not conserved by nuclear weak interactions, they are not necessarily equal.

Expression (1) represents an approximation. Relying on a meson exchange theory of pnc NN forces shows that other terms may be present, depending for instance on the difference of the neutron and proton densities, or containing some non locality (exchange terms) or also a spin-orbit term (kinematical relativisitc corrections). They do not seem to be important and there is presently no need for them. As to the strengths themselves, they can be related to these NN pnc forces, but may as well be considered as parameters to be determined from experiment, thus offering the possibility to perform some kind of model independent analysis of various measurements. /21/

The potential given by (1) is quite appropriate for describing parity-non-conservation in processes involving a single proton or a single neutron moving in the average field produced by other ones. Thus, the study of parity-non-conservation in various electromagnetic transitions in different odd proton nuclei (^{19}F, ^{41}K, ^{175}Lu and ^{181}Ta) provides a rather accurate value of χ^p_N /22/:

$$\chi^p_N = 3.5 \times 10^{-6}. \tag{2}$$

Although it involves a pure nuclear scattering process, the pnc effect observed in proton - α scattering at 15 MeV /23/ seems to be quite consistent with the above value. That strength obviously receives contributions from the proton-neutron and proton-proton forces. The last one is determined by the present measurements of the pnc effect observed in pp scattering /24/. It is found to be 0.8×10^{-6}, a value which is quite reasonable in sign and magnitude since models /25,26/ may more or less account for the part of χ^p_N which is due to the proton-neutron force.

There is no similar information for the strength, χ^n_N . The study of pnc effects in ^{21}Ne may provide some, but nuclear structure of the excited states of interest in this nucleus is not so easy to describe. The dominance of the neutron-nucleus pnc force /27/ is far to be established /28/. Possible, but indirect information may be provided by the width of the level 2^- at 8.88 MeV on ^{16}O /29/, which is measured with good accuracy, or by the radiative decay of the level 0^- at 1.08 MeV in ^{18}F /30/, where no positive effect is seen. Due to well known selection rules, $\Delta T = 0$ in one case, $\Delta T = 1$ in the other, the neutron contribution is accompanied by a proton contribution with the same weight, but an opposite sign. This makes the extraction of X_N^n difficult. The effect observed in ^{16}O suggests a value of X_N^n close to 0, but due to the difficulty to reliably estimate α-decay widths /31/, one cannot exclude $X_N^n \approx X_N^p$. The absence of effect in ^{18}F seems to be more constraining since the possibility to check the theory on the β decay of ^{18}Ne /27/ does not at first sight allow for large uncertainties. It suggests $X_N^p = X_N^n$.

Such a result raises several questions. Some sizeable isovector contribution is expected from the π exchange in some models of the weak NN force /25,32/. On the other hand, if it is not there, it seems difficult to explain the ratio of the contributions to X_N^p of the proton-proton force (0.8×10^{-6}) and the proton neutron force (2.7×10^{-6}) /22/. In the above discussion, which should certainly be moderated, we consider somewhat extreme cases. The difficulties may be alleviated but we do not however believe that they can be completely eliminated.

For our purpose here, we will retain as a reasonable range for X_N^n :

$$0 < X_N^n < 3.5 \times 10^{-6}. \tag{3}$$

The lower value (slightly negative in fact) prevailed in analyses of pnc effects /21,33/ performed before the advent of recent results in ^{18}F /30/. The second value, as explained above, assumes the absence of effect in this nucleus. The lower and upper limits are obviously approximate. They nevertheless are accurate enough for the discussion to be held later on, where only orders of magnitude will be considered.

III. DESCRIPTIONS OF THE SCATTERING STATE

Provided that higher orders in the weak interaction are negligible, one can write the pnc neutron-nucleus scattering amplitude as :

$$f_{pnc} = -\frac{M_r}{2\pi} < \psi^- \mid V_{pnc} \mid \psi^+ > \tag{4}$$

In this expression, M_r represents the reduced mass, V_{pnc}, the pnc force and $|\psi^\pm>$, the scattering state which is supposed to be an eigenstate of the strong interaction hamiltonian :

$$H \mid \psi^\pm > = E \mid \psi^\pm > \tag{5}$$

A good estimate of f_{pnc} therefore supposes a good description of the scattering state, an observation which is truer here than in any other case and justifies some developments.

The scattering state has a neutron-nucleus component, but has also components on the multitude of discrete states which can be admixed to it by the strong interaction and are roughly at the same energy, involving some excitation of the initial nucleus. In this lecture, we will concentrate our attention on the neutron-nucleus component, while trying to incorporate the effect that the discrete states may have on it.

The hamiltonian describing the system under consideration may be written as :

$$H = \sum_i E_i^o \; a_i^+ \; a_i + \int d\vec{r} \; a^+(\vec{r}) \left(\frac{p^2}{2M_r} + V(r)\right) a(\vec{r}) + \int d\vec{r} \sum_i \phi_i(\vec{r}) \, a^+(\vec{r}) \; a_i(\vec{r}) + h.c. \tag{6}$$

The first and second terms respectively describe the discrete states and the nucleon-nucleus component. The last term is relative to their coupling. It involves the function $\phi_i(r)$ which a priori depends on the state and is otherwise expected to be peaked at the nuclear surface, where low energy excitations are likely to be localized.

Quite generally, the solution of the Schrödinger equation (5) may be written as :

$$|\psi^{\pm}> = \int d\vec{r} \; \psi^{\pm}(r) \; a^+(r) \; 0> + \sum \alpha_i^{\pm} \; a_i^+ |0>. \tag{7}$$

It implies coupled equations which are formally easy to solve and lead to the following relations :

$$\alpha_i^{\pm} = \frac{1}{E - E_i^o} \int d\vec{r} \; \phi_i^*(r) \, \psi^{\pm}(r), \tag{8}$$

and

$$\left(\frac{p^2}{2M_r} + V(r) - E\right) \psi^{\pm}(\vec{r}) + \int d\vec{r}' \; W(\vec{r},\vec{r}') \, \psi^{\pm}(\vec{r}') = 0, \tag{9}$$

where

$$W(\vec{r},\vec{r}') = \sum_i \frac{1}{E - E_i^o} \; \phi_i(\vec{r}) \; \phi_i^*(\vec{r}').$$

This last equation is at the core of our concerns. It contains a first term, identical to the Schrödinger equation describing the elastic scattering of a nucleon by some potential, V(r), and a second term, non-local and energy-dependent, which accounts for the coupling of the neutron-nucleus component to discrete states. Not much is known about it, except that its energy average leads to the imaginary part of optical potential models. Those models account for two important quantities : the potential scattering radius, and the strength function. They respectively involve some energy average of the real and imaginary parts of the (strong) scattering amplitude, $a_\ell(E)$:

$$R'_\ell = \frac{1}{\Delta} \int_E^{E+\Delta} dE' \, \mathrm{Re}\, (a_\ell(E')), \tag{10}$$

$$S_\ell = \frac{2p_o}{\pi R_o} \frac{1}{\Delta} \int_E^{E+\Delta} dE' \quad \mathrm{Im}\, (- a_\ell(E')). \tag{11}$$

Taking into account the physics incorporated in optical potential models may be important for our purpose. Unfortunately, the energy average they suppose is not appropriate here, where we look at energy regions in between resonances or around resonances. This is illustrated by predictions for absorption effects at threshold which generally turn out to be much larger than what experiment indicates. We will therefore design a few specific soluble models with the hope they will reproduce the main features that the interaction scattering radius and the strength functions extracted from experiment evidence. This is done in the next section where we will also consider a further model. This one is based on the solution of the optical potential, but with an appropriate modification of its imaginary part.

IV. SOLUBLE MODELS

The first model only includes one resonance in each partial wave. It is identical to the one developed in ref. (18) or also in ref. (17). Once the shape of $\phi(r)$ is chosen, its strength may be chosen to reproduce the properties of the resonances whose closeness is important for enhancing pnc effects. In this model, the potential scattering radius R'_o can go to infinity if the neutron width of the resonance of interest is given a finite value. This is in contradiction with experiment which is essentially represented in fig. 1 by the potential scattering radius calculated from the Buck-Perey optical potential (full line). As it was claimed that such a model could explain some of the pnc effects in neutron-nucleus scattering /17,18/, assuming however favorable conditions, it seems appropriate to include it here.

The second model includes one infinite series of equidistant states with the same coupling $\phi_i(r) = \phi(r)$ $(\forall i)$. The function $\phi(r)$ is taken as

$$\phi(\vec{r}) = - \sqrt{\frac{D}{\pi}} \; \frac{X^{1/2}}{R} \; \frac{df}{dr} \cdot \left(\frac{1}{\sqrt{2M_r}} \; Y_\ell^m(\vec{r})\, i^\ell \right), \tag{12}$$

with $f = (1 + \exp((r-R)/a))^{-1}$, $R = r_o A^{1/3}$, $X = 3\ \mathrm{fm}^{-1}$, $a = 0.65$ fm.
The quantity D appearing in (12) represents the spacing between the discrete states and it is determined by the properties (mainly the width) of the close resonance of interest. It can be compared to the experimental spacing. Contrary to ref. (19), the factor $\sqrt{\frac{\pi}{D}}$ has not been included in $\phi(r)$, hence its appearance in (12).

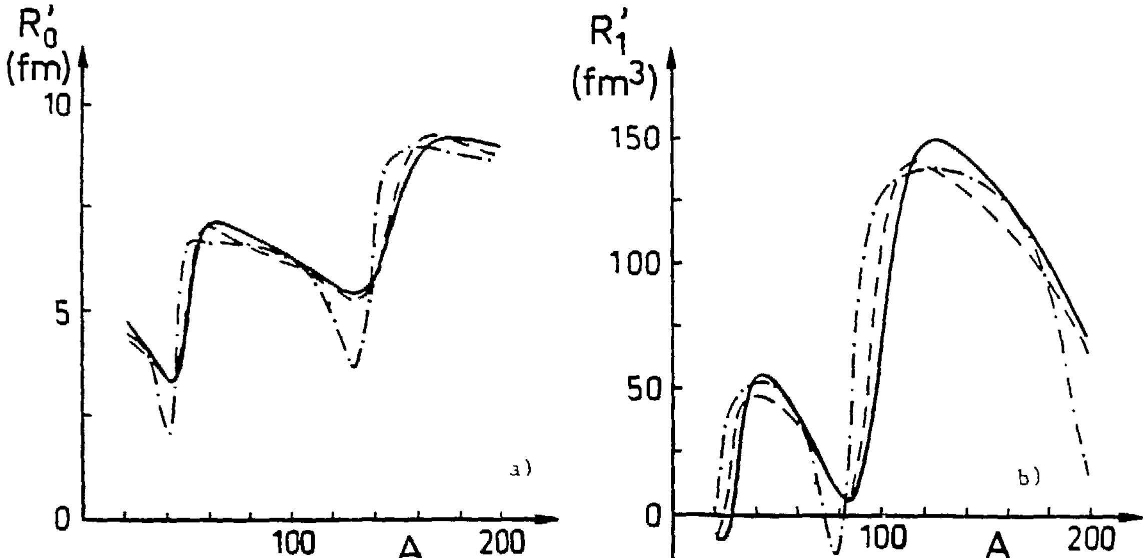


Fig. 1a,b) Potential scattering radius(volume for p-wave) for the Buck-Perey optical potential (full line), the one series of resonance model (dashed-dotted line) and the two series of resonances model (dashed line).

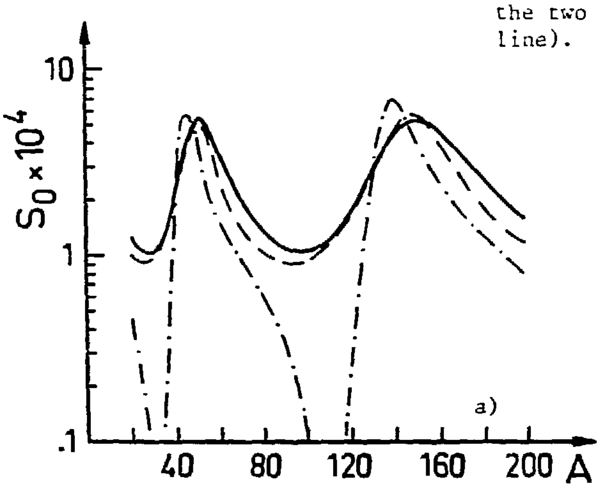
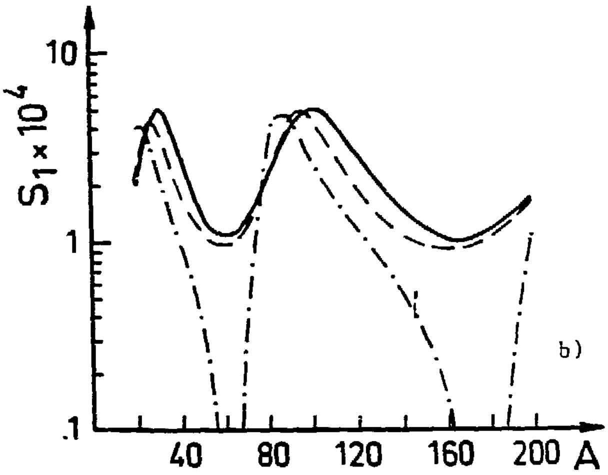


Fig. 2a,b) as in Fig. 1 but for the strength function.



Results of the above model for the potential scattering radii and for the strength functions, which are independent of the average spacing, D, are given in figs. 1a and 1b for the first ones, 2a and 2b for the last ones. At the maxima, the potential scattering radii compare reasonably well with the predictions of the optical potential. Some disagreement appears around the minima where some track of the inert nucleus case (scattering lenght going to infinity) is left. For the strength functions, the agreement is not too bad in the maxima. The minima are completely missed however. It is not difficult to see that this bad feature is due to the fact that the model only contains one type of discrete states, so that the integral $\int dr\, r^2\, \phi(r)\, \psi^+(r)$, which enters in the strength function, vanishes in some cases. Altogether, the coupling of the neutron-nucleus component to an infinite set of discrete states implying the excitation of the nucleus improves the description of some observables over the case of an inert nucleus. One cannot be however completely satisfied by the cancellation of the strength functions for some values of A. To remedy this unpleasant feature, it is clear that different series of discrete states have to be introduced so that integrals $\int dr\, r^2\, \phi_i(r)\, \psi(r)$ do not vanish simultaneously.

The third model contains 2 types of equidistant resonances with an overall average spacing, D. The ϕ functions are now given by :

$$\phi_i(r) = \sqrt{\frac{D}{\pi}}\; \frac{X^{1/2}}{R} \cdot \left[(1 + \exp\,(\frac{r-R}{b}))^{-1}\right]' \cdot \left(\frac{1}{\sqrt{2M_r}}\; Y_\ell^m\,(r)\; i^\ell\right)$$

with $X_1 = 1.7\ fm^{-1}$, $R_1 = R - 0.6\ fm$,

$X_2 = 0.7\ fm^{-1}$, $R_2 = R + 0.6\ fm$, (13)

$b = 0.47\ fm$.

The parameter D is always determined to reproduce the properties of the resonance of interest. This one can be associated with one of the two types of discrete states and there are therefore two possible values for D. These values and the width of the other resonance can be checked against experiment. Results for the potential scattering radius and for the strength function (which are again independent of D) are given in figs. 1-2. They compare very well to the optical model predictions. As a consequence of the non-locality which is built in, they even better account for some experimental data.

At this point, it may be appropriate to give the equation which allows to determine the wave function. In the two series case, it is given by :

$$\left[-\frac{1}{r}\frac{d^2}{dr^2} + \frac{\ell(\ell+1)}{r^2} + 2 M_r V(r) - 2 M_r E\right]\psi_\ell(r)$$

$$+ \frac{\pi}{D_\ell}\left[\mathrm{cotg}\left(\pi\frac{E-E_1^o}{2 D_\ell}\right)\phi_1(r)\int dr' \, r'^2 \phi_1(r') \psi_\ell(r')\right.$$

$$\left. + \mathrm{cotg}\left(\pi\frac{E-E_2^o}{2 D_\ell}\right)\phi_2(r)\int dr' \, r'^2 \phi_2(r') \psi_\ell(r')\right] = 0 \qquad (14)$$

In order to perform the sum over discrete states, we used the relation :

$$\sum_K \frac{1}{E-E_K^o} = \sum_{K=-\infty}^{+\infty} \frac{1}{E-E^o+K D} = \frac{\pi}{D}\,\mathrm{cotg}\left(\pi\frac{E-E^o}{D}\right) \qquad (15)$$

In next section, we will also use wave functions derived from the optical ones as follows :

$$\psi_\ell(r) = \mathrm{Re}\left(\psi_\ell^{opt}(r)\right) - \frac{D}{\pi}\sum_K \frac{1}{E-E_K^o}\,\mathrm{Im}\left(\psi_\ell^{opt}(r)\right) \qquad (16)$$

The real and imaginary parts of $\psi_\ell^{opt}(r)$ are defined such that $\mathrm{Re}(\psi_\ell^{opt}(r))$ behaves asymptotically as :

$$\mathrm{Re}\left(\psi_\ell^{opt}(r)\right) \underset{r\to\infty}{\rightarrow} j_\ell(pr) - p^{2\ell+1} R'_\ell \, n_\ell(pr) \qquad (17)$$

Appropriate phase and normalisation factors should be included in calculating the weak amplitude (4) so that to describe incoming or outcoming states. The relevance of the formula (16) has been discussed at length in ref. (19). We will here retain that it acts as an average of possible expectations.

V. P.N.C. OBSERVABLES-WEAK AMPLITUDE

Several different pnc effects are observed in nuclear processes involving thermal neutrons. Those considered here will be dealing with the forward elastic scattering amplitude, which can be parametrized as :

$$f_{p.n.c.}(0°) = G' < \vec{\sigma}_n \cdot \vec{p}_n > \qquad (18)$$

The different observables of interest in such a case are the spin rotation[11] per unit of length of the material that the neutron has gone through :

$$\phi/\ell = -4\pi \, \rho_{mat} \, \mathrm{Re}(G') \qquad (19)$$

where ρ_{mat} represents the sample density, and the asymmetry in the cross-section for circularly polarized neutrons :

$$P(E) = \frac{\sigma(+) - \sigma(-)}{\sigma(+) + \sigma(-)} = 4\pi \quad Im\,(G')/\sigma \,. \tag{20}$$

Two values of this asymmetry are particularly interesting, at threshold, P (0) , and at the P-wave resonance energy, P (E_p)

The single particle contribution, which is at the center of our concerns throughout this paper, can be calculated from eq. 9 in the general case or from an equation identical or similar to eq. 14 in the case of soluble models we made. It is given by :

$$G'_{s.p.} = - \frac{4\pi M_r}{M^3} \; X_N^n \; \frac{g}{p} \int_0^\infty dr\, r^2 \rho(r) \left(\psi_0 \frac{d}{dr}\psi_1 - \frac{d}{dr}\psi_0 \psi_1 + \frac{2}{r}\psi_0 \psi_1\right), \tag{21}$$

where $g = (2J + 1) / (2(2I + 1))$. (J is the spin of the resonance and I that of the target nucleus). The nuclear density is defined in (21) such that $\int d\vec{r}\; \rho(r) = A$.

Anticipating on the last section, we also give the expression for the compound nucleus contributions :

$$G'_{c.n.} = - \frac{M_r}{2\pi} \Sigma\, \alpha_m^{-*} < m \mid V_{p.n.c.} \mid n > \alpha^+_n, \tag{22}$$

where the coefficients $\alpha^{\pm}$ are given by (8).

VI. RESULTS AND DISCUSSION

We will successively consider two sets of results. The first one (Table I) is devoted to the study of their sensitivity to different inputs and, in this aim, we choose the ^{117}Sn nucleus which turns out to be very instructive with this respect. In the second set (Table II), results for different nuclei are given. They should allow to conclude whether it is reasonable to describe pnc effects in neutron-nucleus scattering by relying on the neutron-nucleus component. In all cases, the quantity we will discuss is the strength X_N^n which reproduces the experimental data within some model. It is given in the tables.

As it can be seen in Table I, the dependence on the parameter r_o which determines the radius of the Woods-Saxon potential is quite large in the two first models (one resonance and one series of resonances). This is due to the proximity of the threshold for binding a neutron in the 2p-orbit. Its effect lowers the value of X_N^n to a level compatible with expectations, thus providing one of the examples where favorable circumstances make possible an explanation of pnc effects in neutron-nucleus scattering from the neutron-nucleus component. The dependence has almost disappeared in the two series of resonances model. In this case, two values are given for each

TABLE I

Study in ^{117}Sn of the sensitivity of the results to different inputs : Woods-Saxon potential, approximations (see text) and observables. The contents of the table represents the values of X_N^n which, depending on the input, reproduce measurements for a few observables (given at the bottom of the table)

Approximation		$X_N^n \times 10^6$		
1) 1 resonance	r_o = 1.27 fm	-92	-370	-300
	r_o = 1.25 fm	- 0.84	-2.1	- 3.3
2) 1 series of resonances	r_o = 1.27 fm	267	292	2980
	r_o = 1.25 fm	- 0.84	-2.1	- 3.3
3) 2 series of resonances	r_o = 1.27 fm	4.7	11	18
		11.5	27	45
	r_o = 1.25 fm	5.5	13	21
		18	42	71
Observable →		P(0) /34/ = (6.2±0.7) x 10^{-6}	$P(E_p)$ /3/ = (4.5±1.3) x 10^{-6}	ϕ/ℓ /35/ = (-37.0±2.5) x 10^{-6} rad/cm

value of r_o. They correspond to assigning the resonance to one or the other types we introduced for them. There is some sensitivity, but it is now rather limited. Finally, if the present approach makes sense, the value of X_N^n extracted from measurements should be the same whatever the observable. The large deviations we observe may then lead to dismiss the present approach. However, the other approach described in next section does not do much better and other inputs have therefore to be incriminated. Experimental data may be wrong (a value of $P(E_p)$ of (7.7±) x 10^{-6}, which fits better with ϕ/ℓ , has been mentioned by P.A. Krupchitski in his talk at the present meeting), or a second resonance may play a non-negligible role.

Table II

Comparison of the values of X_N^n obtained from different observables for various nuclei. Depending on which of the two types of resonances we associate with the observed one, there are two values in some cases (and correspondingly two values of D_o). Results for the appropriately modified optical model wave function are given in parentheses.

Nucleus		$X_N^n \times 10^6$		
^{81}Br	D_o = 120 eV	81	66	
	D_o = 420 eV	330	280	
	(opt. model)	(180)	(150)	
^{111}Cd	D_o = 230 eV		- 57	
	D_o = 520 eV		1400	
	(opt. model)		(-113)	
^{117}Sn	D_o = 540 eV	4.7	11	18
	D_o = 470 eV	11.5	27	45
	(opt. model)	(12)	(30)	(48)
^{139}La	D_o = 160 eV	-402	-456	-587
	(opt. model)	(-155)	(-177)	(-221)
Observable →		P(0) /34,36/	$P(E_p)$ /3/	ϕ/ℓ /35/

In Table II, we report the values of X_N^n which correspond to acceptable values of the spacing D_o (S-wave). They are generally in reasonable agreement with those using the wave function appropriately built from the optical model one (within a factor 2-3). The only exception is ^{111}Cd where again the proximity of the threshold to bind a neutron in the 2p-shell plays an important role. This is not however to change the conclusions. The values of X_N^n necessary to reproduce experimental data are quite different in signs and in magnitudes. No unique value emerges from the comparison of results in different nuclei. Furthermore, the magnitude which is required is one or two orders of magnitude larger than what is expected (eq. 3).

Discarding some favorable circumstances, which are likely to be highly accidental, we conclude that the parity admixture at the level of the neutron-nucleus component cannot explain those large pnc effects observed in the scattering of neutrons on medium and heavy nuclei.

VII. THE OTHER INTERPRETATION

Due to the coupling of the different discrete states through the neutron-nucleus component, expression (22) of the compound-nucleus contribution to G', $G'_{c.n.}$, does not evidence the simple behavior relative to one resonance. Different contributions have first to be gathered . Once this is done, $G'_{c.n.}$ can be written as :

$$G'_{c.n.} = \sum_{ij} g \sqrt{\frac{\Gamma^n_{s_j} \; \Gamma^n_{p_i}}{p_{s_j} \; p^3_{p_i}}} \; \frac{\langle \tilde{s}_j \mid V_{p.n.c.} \mid \tilde{p}_i \rangle}{(E-E^s_j + \frac{i}{2}\Gamma_{s_j})(E-E^p_i + \frac{i}{2}\Gamma_{p_i})} \qquad (23)$$

In eq. 23, the states $|\tilde{s}\rangle$ and $|\tilde{p}\rangle$ represent linear combinations of the discrete states initially introduced in the Hamiltonian, eq. (6)

In the case where one resonance dominates for each partial wave in (23), simple relations may be derived /7,9,10/ :

$$\frac{P(0)}{\phi(m.f.p.)} = - \frac{Im\,(G')}{Re\,(G')} = - \left(\frac{\Gamma_p}{2\,E_p} + \frac{\Gamma_s}{2\,E_s} \right), \qquad (24)$$

and

$$\frac{P(E_p)}{P(0)} = \frac{\sigma_{th.}}{\sigma_{res.}} \cdot \frac{Im(G')_{E=E_p}}{Im(G')_{E=0}} = \frac{\sigma_{th.}}{\sigma_{res.}} \left(\frac{2\,E_p}{\Gamma_p} \right)^2, \qquad (25)$$

where Γ_p and Γ_s represent the widths of the resonances and E_p and E_s their energies. In principle, the above relations may be used to test the validity of the approach. It turns out that they are almost equally verified by the valence model, due to the dominance in it of the resonant part of the neutron-nucleus component. As already mentioned, results in ^{117}Sn do not satisfy the above relations, which may be due to an inaccurate experimental result or to the absence of other resonance contributions in the analysis. The adequacy of the present approach cannot therefore be only established on checking whether measurements obey eqs. 24-25.

The other information which may be considered is the value of the weak matrix element appearing in the numerator of the right hand side of eq. 23. Due to the fact that it involves a very large number of contributions, no accurate estimate can be made. On the other hand, we expect signs of those individual contributions to be at random and hence some suppression of the matrix elements. However, the suppression is not so strong as what one would naively expect by assuming that signs are successively positive and negative. In such a case, the matrix element would be equal to a typical one-body or two-body matrix element of the weak force divided by the number of components in the wave function, N. If signs are really at random, it turns out that one has to divide by the square root of N[4,5]. This number may be related to the density of states and to some energy range.

Without entering into the details of the estimate, which in any case should be greatly refined, one thus may get :

$$\overline{|\langle \tilde{s} | V_{p.n.c.} | \tilde{p} \rangle|} = |H'_{s.p.}| \frac{1}{\sqrt{N}}$$

$$= 0.5 \text{ eV} \times (10^{-3} - 10^{-2}) = (0.5 - 5) \text{ meV} \qquad (26)$$

In the above equation, the single particle matrix element has been taken as the one which in ^{19}F determines the pnc effect observed in the radiative decay of the level $1/2^-$ at 110 keV[27]. It involves a transition between states $1/2^-$ and $1/2^+$. It should be clear that the estimate (26) relies on a statistical basis. The sign is unknown and the magnitude may vary in some range. To get an accurate value of $\langle \tilde{s} | V_{p.n.c.} | \tilde{p} \rangle$, a large statistics would be necessary. On the other hand, we only considered a proton single particle matrix element in (26). At some point, the neutron single-particle matrix element and two-body matrix elements not incorporated in the single-particle matrix element should enter into the estimate.

The comparison of the experiment with the above estimate is quite satisfying. Results obtained from the measurement of the asymmetry at the resonance[31,37] are :

$$\begin{aligned}
^{81}\text{Br} &: \langle \tilde{s} | V_{p.n.c.} | \tilde{p} \rangle &&= (3.0 \pm 0.5) \text{ meV}, \\
^{111}\text{Cd} &: \langle \quad " \quad \rangle &&= (0.80 \pm 0.22) \text{ meV}, \\
^{117}\text{Sn} &: \langle \quad " \quad \rangle &&= (-0.38 \pm 0.10) \text{ meV}, \\
^{139}\text{La} &: \langle \quad " \quad \rangle &&= (-1.20 \pm 0.12) \text{ meV}. \qquad (27)
\end{aligned}$$

All the numbers are in the expected range and one can conclude that the parity admixture at the compound nucleus level reasonably accounts for pnc effects observed in scattering of neutrons on medium-heavy nuclei.

CONCLUSION

In this lecture, we considered the tentative explanation of pnc effects in neutron-nucleus scattering based on parity admixture at the level of the neutron-nucleus component. Punctually, such an approach succeeded in the past for accounting for some pnc effects in heavy nuclei. Favorable circumstances had however to be realized. Better treatment, including the coupling of the neutron-nucleus component to an infinity of different discrete states rules out such an explanation. Not only there is no value of the strength of the neutron-nucleus weak force able to explain simultaneously data in several nuclei, but also, the values which come out for this strength are one or two orders of magnitude larger than expected. As a consequence, the proposal to look at pnc effects in scattering of neutrons on medium-heavy nuclei to learn about the intensity of the pnc neutron-nucleus force is also ruled out.

The only explanation left for accounting for those effects is based on parity admixture at the compound nucleus level. This approach sounds quite reasonable, but, obviously, it can only provide vague information on pnc nucleon-nucleon forces.

In this lecture, we have only considered a limited number of pnc effects. We did not consider in particular those seen in fission or in radiative capture which the second explanation seems to account for although a few physicists still express some reserve about it.

During the discussion following the lecture, it was reminded that the measurement of the anapole moment [38] of nuclei may give the information we looked for. It seems however that present candidates are odd-proton nuclei and not odd-neutron nuclei. On the other hand, results similar to those obtained here with appropriately modified optical model wave functions, but perhaps more rigorous, have been presented at this meeting by Drs M.G. Urin and O.N. Vayzankin [39].

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