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WHY IS THE ISOSCALAR ρ EXCHANGE CONTRIBUTION TO THE CIRCULAR POLARISATION IN $n + p \to d + \gamma$ ALMOST ZERO?

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ABSTRACT

It is shown that the smallness of the contribution of the isoscalar part of the parity violating ρ exchange potential to the circular polarisation of the photon emitted in the reaction $n + p \to d + \gamma$ is a consequence of the low energy peak of the E1 excitation spectrum of the deuteron.

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Since 1974 a large number of exact calculations of the parity violating observables in the reaction $n + p \rightarrow d + \gamma$ have been made[1-14]. In these calculations, which have been done with a wide variety of strong interaction potentials, the most striking result is the fact that the contribution of the isoscalar part of the ρ exchange potential to the circular polarisation is much smaller than that of the other vector meson exchange potentials†. In fact, even the sign of the contribution of the isoscalar part of the potential changes as the strong interaction is varied. This effect is illustrated in table I, where the weak parity violating potential is defined as in ref. 1, as are the potential parameters H, K and L, which determine the isoscalar potential

$$V_{pv}^{(0)} = (2H+K)V_\rho \, \underset{\sim}{\tau}_1 \cdot \underset{\sim}{\tau}_2 + L \, V_\omega \, \underset{\sim}{1} \qquad (1)$$

($\underset{\sim}{1}$ is the unit operator in isospin space)

and the isotensor potential

$$V_{pv}^{(2)} = (K-H) \, V_\rho \, (3\tau_{1z}\tau_{2z} - \underset{\sim}{\tau}_1 \cdot \underset{\sim}{\tau}_2) \qquad (2)$$

where

$$V_\rho = - \frac{GG_A m_\rho^2}{4\pi\sqrt{2}m_N} \left(\{ \underset{\sim}{p}, \frac{e^{-m_\rho r}}{r} \} \cdot (\underset{\sim}{\sigma}_1 + \underset{\sim}{\sigma}_2) + (1+\mu_V) \, i\underset{\sim}{\sigma}_1 \times \underset{\sim}{\sigma}_2 \cdot [p, \frac{e^{-m_\rho r}}{r}] \right) \qquad (3)$$

$$V_\omega = - \frac{GG_A m_\omega^2}{4\pi\sqrt{2}m_N} \left(\{ \underset{\sim}{p}, \frac{e^{-m_\omega r}}{r} \} \cdot (\underset{\sim}{\sigma}_1 + \underset{\sim}{\sigma}_2) + (1+\mu_S) \, i\underset{\sim}{\sigma}_1 \times \underset{\sim}{\sigma}_2 \cdot [\underset{\sim}{p}, \frac{e^{-m_\rho r}}{r}] \right) \qquad (4)$$

We do not specify the isovector potential since it contributes to the circular polarisation only in pathological cases[1].

The purpose of this note is to offer a qualitative explanation of this feature of the calculations, which identifies the underlying physics and shows that the result is not accidental, but should occur in all such calculations.

It has been observed by most of the authors cited above that the $\underset{\sim}{\tau}_1 \cdot \underset{\sim}{\tau}_2$ term is small because the contributions to P_γ from the processes

$$^1S_0 \overset{pv}{\leftrightarrow} {}^3P_0 \overset{E1}{\rightarrow} {}^3S_1,\ {}^3D_1$$

and $$^1S_0 \overset{E1}{\rightarrow} {}^1P_1 \overset{pv}{\leftrightarrow} {}^3S_1,\ {}^3D_1$$

tend to cancel for both the $\underset{\sim}{\tau}_1 \cdot \underset{\sim}{\tau}_2$ and the $\underset{\sim}{1}$ parts of the potential, but that the cancellation is usually more complete in the former case.

If $\underset{\sim}{D} = \frac{e}{4} (\underset{\sim}{r}_1 - \underset{\sim}{r}_2)(\tau_{1z} - \tau_{2z})$ is the electric dipole operator, we can write for the irregular E1 matrix element $\langle E1 \rangle$,

$$\begin{aligned} \langle E1 \rangle &= \langle d | \underset{\sim}{D} \frac{1}{E_i - H_s} V_{pv} | i \rangle \\ &+ \langle d | V_{pv} \frac{1}{E_d - H_s} \underset{\sim}{D} | i \rangle . \end{aligned} \tag{5}$$

The notation $|i\rangle$ and $|d\rangle$ is used for the initial $^1S_0$ scattering state and the final $^3S_1$, $^3D_1$ deuteron state, which have energies $E_1 \approx 0$ MeV and $E_d = -B \approx -2.2$ MeV. To estimate these matrix elements we introduce the closure approximation, assuming that the mean excitation energy $\bar{E}$ is the same for each of the terms in (5)

$$\langle E1 \rangle = - \frac{1}{\bar{E}} \langle d | \underset{\sim}{D} V_{pv} | i \rangle - \frac{1}{B+\bar{E}} \langle d | V_{pv} \underset{\sim}{D} | i \rangle . \tag{6}$$

Next we insert the various potential components of equations (1) and (2) and evaluate the isospin matrix elements, defining

$\underset{\sim}{D}_s = \frac{e}{2} (\underset{\sim}{r}_1 - \underset{\sim}{r}_2)$.

$$\langle \bar{E}1 \rangle = e_1(2H+K) + e_2(K-H) + e_3 L \tag{7}$$

$$e_1 = -\left\{\frac{1}{\bar{E}} \langle d|\underset{\sim}{D}_s V_\rho|i\rangle - \frac{3}{\bar{E}+B} \langle d|V_\rho \underset{\sim}{D}_s|i\rangle\right\} \tag{8a}$$

$$e_2 = \frac{4}{\bar{E}} \langle d|\underset{\sim}{D}_s V_\rho|i\rangle \tag{8b}$$

$$e_3 = -\left\{\frac{1}{\bar{E}} \langle d|\underset{\sim}{D}_s V_\omega|i\rangle + \frac{1}{\bar{E}+B} \langle d|V_\omega \underset{\sim}{D}_s|i\rangle\right\} \tag{8c}$$

To make further progress we need an estimate of $\bar{E}$. It has been suggested that $\bar{E}$ is much greater than B.[6] We argue that this is not the case, and that, in fact $\bar{E} \sim B$. Our argument is based on a number of observations:

(i) From observations of the photoelectric disintegration of the deuteron, we see that $\sigma(E) \propto E|\langle E|\underset{\sim}{D}|d\rangle|^2$ has a sharp maximum for $E \sim B$[15].

(ii) The $\frac{1}{E}$ factor in equation (3) tends to push the maximum to lower energies.

(iii) While at first sight $\langle E|V_{pv}|i\rangle$ would be expected to favour high energy excitations, this effect is supressed by the short range correlations in the wave function. Moreover any tendency to excite high energy intermediate states is countered by effects (i) and (ii).

(iv) Application of our arguments, with the hypothesis $\bar{E} \gg B$ to the asymmetry A_γ leads to the erroneous conclusion that the π exchange contribution to A_γ should vanish. It is not even anamolously small.

With the assumption $\bar{E} = B$, the assumption that $\langle d|\underset{\sim}{D}_s V_{\rho,\omega}|i\rangle = \langle d|V_{\rho,\omega} \underset{\sim}{D}_s|i\rangle = M_{\rho,\omega}$ which is strictly true only for the local part of $V_{\rho,\omega}$, and the further assumption that $M_\rho = 4M_\omega = M$, which is suggested by the ratio of the magnetic moment couplings of the ρ and ω.

$$\langle\bar{E}1\rangle \propto \frac{M}{B}\left\{\tfrac{1}{2}(2H+K) + 4(K-H) - \frac{3}{S}L\right\}$$

giving $e_1:e_2:e_3 = -1.33:-10.6:1$, which is to be compared to the ratios $p_1:p_2:p_3$ in table I. The ratio $p_1:p_3$ from the detailed calculations is usually less than or of the order of one and moreover it fluctuates in sign, showing that the cancellation is almost complete and that the final result is sensitive to the strong potential used.

The sign of the ratio $p_2:p_3$ is correctly predicted by our simple model, but its magnitude is too small in the model. Nevertheless, the agreement is sufficient to convince us of the physical reasonableness of our picture. Moreover, it permits us to understand the extreme sensitivity of e_1 to the strong interaction since it changes sign at $\bar{E} = \tfrac{1}{2}B$. Small changes in $\bar{E}$ produce dramatic effects on e_1, but much smaller effects on e_2 and e_3.

To conclude, we emphasise that the observed near cancellation of the contribution to P_γ in $n + p \to d + \gamma$ from the ρ exchange part of the weak nucleon-nucleon potential proportional to $\tau_1 \cdot \tau_2$ is a consequence of

(i) the isospin structure of the weak potential, and

(ii) the fact that the E1 excitations of the deuteron are predominantly at low energy.

As such it will occur for any strong potential which gives a reasonable representation of the properties of the two nucleon system and is not simply an accidental feature of the existing calculations.

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† There are a few cases in which the isoscalar ρ potential makes a contribution to P_γ of the same order as that of the ω exchange potential. These can be understood in terms of the sensitivity of $P_\gamma^{(\rho)}$ to the mean excitation energy $\bar{E}$ introduced here. In one case of ref. 14, the isoscalar ρ dominates the isotensor contribution. This indicates a pathology of the strong potential used there, which cannot be understood as it was not specified in sufficient detail.

TABLE I

Results of Calculations of P_γ in $n + p \rightarrow d + \gamma$

We write $P_\gamma = p_1(2H+K) + (K-H) + P_3 L$ in the notation of ref. 1.

Calculation: Ref.	Calculation: Strong Potential	$10^3\ p_1$	$10^3\ p_2$	$10^3\ p_3$	$p_1:p_2:p_3$
Lassey-McKellar ref. 1-4	RPSC ref. 16	-0.044	-2.40	0.057	-0.77:-42:1
	GPD ref. 17	0.106	-5.55	0.376	0.28:-14:1
	GTG ref. 18	-0.026	-3.66	0.128	-0.20:-29:1
	EHM ref. 19	0.188	-3.50	0.129	1.5 :-27:1
Desplanques (a) ref. 5	HJ ref. 20	0.15	-2.2		
	RSC ref. 16	-0.05	-2.2		
	TS ref. 21	-0.7	-3.5		
Pisner-Rustgi ref. 6-8	RSC ref. 16	-0.047	-2.19	0.056	-0.84:-39:1
	RHC ref. 16	0.163	-2.33	0.126	1.29:-18:1
	HJ ref. 20	0.099	-2.20	0.074	1.3 :-30:1
	Y ref. 22	0.240	-2.32	0.074	3.2 :-31:1
	MY ref. 22	-0.523	-2.45	0.124	-4.2 :-20:1
Gari-Schlitter ref. 9,10	HJ ref. 20	0.111	-2.28	0.188	0.59:-12:1
	RSC ref. 16	-0.078	-2.26	0.116	-0.67:-19:1

Calculation		10^8 p_1	10^8 p_2	10^8 p_3	p_1:p_2:p_3
Ref.	Strong Potential				
Gari-Schlitter ref. 9,10 continued	TS_1 ref. 21	-0.456	-4.21	0.452	-1.0 :-93:1
	TS_2 ref. 21	-1.37	-4.13	0.428	-3.2:-9.6:1
Carver et al ref. 11-13	RSC ref 16	-0.049	-2.37	0.081	-0.60:-20:1
	Case A S-D states transformed	-0.091	-1.36	-0.019	4.8 : 71:1
	Case B P states transformed	-0.148	-1.86	0.031	-4.8 : 60:1
	Case C All states transformed	4.50	-16.8	-0.89	-5.1 : 19:1
Ohya et al ref. 14	HJ ref. 20	0.17	-2.64	0.25	0.68:-10.6:1
	KSW ref 24	-0.69	-1.91	0.33	-2.1 :-5.8:1
	T ref. 25	1.04	-0.96	0.35	3.0 :-2.7:1

(a) Desplanques does not publish results which permit the extraction of p_3

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   Note that the values of p_3 and $d_{\ell i}$, in tables VI and VII of this paper should be multiplied by 2.

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