AXIAL STRANGENESS CURRENT EFFECTS IN SOLAR NEUTRINO DETECTION*

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Abstract

The results on the spin structure of the proton suggest the presence of an axial strangeness current interaction. This would modify the assumed transition strengths for the analysis of the solar neutrino experiments sensitive to neutral currents. In the long wavelength limit a deuterium target is insensitive to such a mechanism. In the planned BOREX experiment the isoscalar strength would increase the observed rate by 30-40%, associated mainly with the neutrino-proton component.

INTRODUCTION

As it stands now, it is impossible to decide from only charged-current detection of the solar neutrinos, as probed in the ³⁷Cl Homestake, Kamiokande-III and ⁷¹Ga SAGE and GALLEX experiments¹, whether the solar neutrino problem is due either to basic properties of the neutrino or to the shortcomings of the standard solar model.

The topic of the present talk concerns the interpretation² of the neutral-current solar neutrino experiments, from the simultaneous comparison of charged and neutral current determinations of the solar neutrino flux. Neutral current reactions proceed with the same cross-section for all neutrino flavours, whereas charged-current transitions are induced by left-handed electron neutrinos only. Let me first briefly review the characteristics of the neutral current experiments that are planned or in progress.

The Sudbury experiment in Canada (SNO)³

The experiment is based on a large heavy-water detector and aims at detecting the deuteron break-up charged and neutral currents processes. In addition, it will detect the elastic ν scattering from electrons, sensitive to charged current and, to a lesser extent, to neutral current interactions.

The BOREX Collaboration in Gran Sasso¹

This experiment uses a calorimetric boron liquid scintillator detector and aims at the detection of the charged and neutral currents processes in ¹¹B. The first smaller version of the detector, BOREXINO⁵, will put the emphasis on the reactions on free protons and electrons. The detailed calculations of the axial neutral current transition strengths had assumed that these transitions are purely of the isovector type^{6,7}. However, the EMC

*Talk presented by J. Bernabéu at ICHEP-92, Dallas, August 1992.

experiment⁸ suggests that there is also a non-vanishing isoscalar axial component, associated to the neutral strangeness current. The question is then:

-How will this isoscalar axial current change the analysis of these experiments?

-Which are the supplementary experiments which are needed and which must be planned now for a proper interpretation?

PROTON SPIN AND NEUTRAL CURRENTS

This section points out the evidence for a neutral current axial isoscalar coupling from the EMC experiment. The first moment of the spin-dependent structure function of the proton leads, by means of the Bjorken's sum rule⁹, to the measurement of the helicity carried by the different quarks (and antiquarks) in the proton, weighted by the appropriate q_i^2 , the square of the electric charge of each quark. Other two independent combinations of the polarized quark moments are determined by the baryon semileptonic decays. The flavour-U(3) amplitudes have thus the couplings

$$G_A^{(3)} = 1.254 \pm 0.006; G_A^{(8)} = 0.68 \pm 0.04; \\ G_A^{(u)} = 0.12 \pm 0.17 \quad (1)$$

The result for the singlet polarized moment $G_A^{(0)} \equiv G_A^{(u)} + G_A^{(d)} + G_A^{(s)}$ indicates that the total helicity carried by quarks in a polarized proton is small.

The weak neutral current operator contains an axial component given by

$$J_{\lambda}^{A,Z} = \bar{\Psi}_u \gamma_{\lambda} \gamma_5 \Psi_u - \bar{\Psi}_d \gamma_{\lambda} \gamma_5 \Psi_d - \bar{\Psi}_s \gamma_{\lambda} \gamma_5 \Psi_s \quad (2)$$

so that a non-vanishing expectation value of the last term for the proton will induce an axial isoscalar coupling $G_A^{(s)}$.

Using the estimates (1), the axial neutral

current coupling of the proton is given by

$$G_A^{(p)} = G_A^{(u)} - G_A^{(d)} - G_A^{(s)} = 1.44 \pm 0.06$$

In terms of nucleonic axial neutral currents there is therefore, in addition to the well known isovector coupling g_A , an isoscalar coupling f_A , such that

$$g_A = \frac{1}{2}[G_A^{(p)} - G_A^{(n)}] = 1.254 \pm 0.006 \\ f_A = \frac{1}{2}[G_A^{(p)} + G_A^{(n)}] = 0.19 \pm 0.06 \quad (3)$$

It is the last term that is the new one.

For solar neutrino interactions we only need the Non-Relativistic Long-Wave-Length limit for the Nuclear Neutral Current and the coupling does not depend on the neutrino flavour.

NEUTRINO DISINTEGRATION OF THE DEUTERON

This problem has been discussed in detail by several authors⁶ for low energy neutrinos under the assumption that only the isovector component contributes to the axial current. They find that in this case the predominant transitions occur almost entirely as allowed Gamow-Teller transitions, i.e. by the axial current interaction to the isospin 1 singlet state ($^1S_0; I = 1$) of the two-nucleon system.

The unretarded nucleonic transition operators which appear in the long wavelength limit are

$$\sum_i 1^i : \sum_i \tau_3^i \quad (4)$$

for the isoscalar and isovector vector currents, and

$$\sum_i \vec{\sigma}^i ; \sum_i \vec{\sigma}^i \tau_3^i \quad (5)$$

for the isoscalar and isovector axial currents.

The identity operator is incapable of producing inelastic transitions. The isovector vector operator is identical to the third component of the isospin and can only produce elastic amplitudes. For an isospin 0 nucleus such as the deuteron, the isovector vector operator gives a null result in all cases. The isoscalar axial operator is proportional to the total spin carried by the nucleons. For the special case of the deuteron which is a nucleonic spin triplet state $^3S_1 + ^3D_1$, spin is a good quantum number; the spin operator with no spatial component can then only reorient the deuteron but does not lead to inelastic transitions. Consequently we reach the important conclusion that the axial isoscalar neutral-current interaction is ineffective for solar neutrinos incident on a deuterium target such as the heavy-water detector of the Sudbury experiment. Finally, the effect of the axial isovector current is to convert the deuteron $S = 1, I = 0$ state to the $S = 0, I = 1$ state without modifying the spatial wave function. The corresponding excitations are the ones of the broad singlet structure in the p-n system, extending for several MeV near threshold.

NEUTRINO TRANSITIONS IN THE $^{11}\text{B} - ^{11}\text{C}$ SYSTEM

The $A = 11$ system is particularly suited to the method of comparing the neutral current excitation of nuclear levels with the conventional charged-current transitions. The scheme of levels and relevant transitions in the $^{11}\text{B} - ^{11}\text{C}$ system is presented in Fig. 1.

The transition operators are like for the deuteron case: the operators of Eqs. (4) and (5). The transitions to excited states are all purely axial ones. The isovector current matrix elements can be "directly" determined. The transition rate to the ^{11}C ground state depends on $\sum_i \tau_i^z$, with known matrix element.

Figure 1. The $^{11}\text{B} - ^{11}\text{C}$ mirror nuclear system. The energies are in MeV. The excitations of ^{11}C from ^{11}B (g.s.) are denoted by CC (charged current) and the excitations of ^{11}B from ^{11}B (g.s.) by NUEX (neutral excitations).

and $g_A \sum_i \vec{\sigma}_i \tau_i^z$, which is determined from the ^{11}C β -decay. The Gamow-Teller transition rates to the excited states $^{11}\text{C}^*$ follow from the corresponding forward (p,n) charge-exchange cross sections normalized to the value from β -decay. The isovector neutral current matrix elements of $g_A \sum_i \vec{\sigma}_i \tau_i^z$ to $^{11}\text{B}^*$ follow by isospin symmetry from the charged current ones. The isoscalar axial transition operator is $f_A \sum_i \vec{\sigma}_i$. It can be determined from the magnetic M1 γ transition rates from excited states to the ground state in ^{11}B and ^{11}C . Using the present information on the M1 rates and a theoretical description of ratios of matrix elements in terms of Cohen-Kurath wave functions ¹⁰ we can determine² for all the transitions involved

$$\frac{\langle \sum_i \vec{\sigma}_i \rangle}{\langle \sum_i \vec{\sigma}_i \tau_i^z \rangle} \approx 1 \quad (6)$$

The result (6) means that the neutral current transitions in ^{11}B are proton dominated, that is, the excited states are simply recouplings of the three valence protons, while the neutrons are nearly unaffected by the allowed axial current operator.

Expectations for the rates of the charged

J^π	$\sigma_c(10^{-44} \text{ cm}^2)$	$\sigma_N(10^{-44} \text{ cm}^2)$
$3/2^-$	98.2	-----
$1/2^{*-}$	20.9	$7.52[1 + 1.25(f_A/g_A)]^2$
$5/2^{*-}$	8.4	$3.58[1 + 1.02(f_A/g_A)]^2$
$3/2^{*-}$	7.2	$3.10[1 + 1.15(f_A/g_A)]^2$

Table 1. Charged and neutral current cross sections in the $^{11}\text{B} - ^{11}\text{C}$ system, averaged over the incident solar neutrino spectrum.

and neutral current transitions are given in Table 1.

The last column confirms our conclusion that the neutral transitions are proton dominated, which would correspond to a characteristic factor $[1 + (f_A/g_A)]^2$. This represents a 30-40% increase of the neutral current rate, when the values (3) are used.

CONCLUSIONS

The presence of an axial isoscalar neutral current interaction can be potentially important for the determination of the solar neutrino flux. It is special that a deuteron target is not affected by this mechanism, so that the transitions relevant to the SNO-experiment are controlled by the isovector current. The BOREX detector, on the other hand, is sensitive in its neutral current signals to the axial isoscalar component and the corresponding cross sections may be increased by 30-40%.

The following priorities should be set for complementary experiments:

1.- To determine f_A/g_A from elastic $\nu p \rightarrow \nu p$ cross section, as suggested by several authors¹¹, and such an experiment is underway at LAMPF. More precise information on the spin-dependent structure function of the proton, as envisaged by SMC (CERN), HERMES (HERA) and E142 (SLAC) experiments, is welcome.

2.- To determine the transition matrix elements the $M1 \ ^{11}\text{C}^* \rightarrow ^{11}\text{C} + \gamma$ rates should be measured, as well as the forward $^{11}\text{B}(p,n)^{11}\text{C}^*$ cross sections to definite states.

Acknowledgements

This work has been supported in part by CICYT under Grants AEN90-0040 and AEN90-004.

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