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ELEMENTARY PARTICLE APPROACH TO BETA DECAY AND MUON CAPTURE
IN THE $A = 12$ NUCLEI

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A B S T R A C T

In this paper a test of CVC is presented for the nuclear system $A = 12$ based on the $f\tau_{1/2}$ value of β^- decay of ^{12}B , the muon capture rate on ^{12}C and the average nuclear polarization of the recoiling nucleus in this last process. The nuclei are treated as elementary particle and in this way all problems related to the calculation of nuclear matrix elements are avoided. Furthermore these experimental values and the use of PCAC allow us to draw some conclusions on the shape factor slope and asymmetry parameter of the β^- decay of ^{12}B .

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1. - INTRODUCTION

Nearly twenty years have elapsed since Feynman and Gell-Mann ¹⁾ devised the so-called conserved vector current (CVC) theory and Gell-Mann ²⁾ proposed to measure high energy beta-ray spectra to test it. He considered as particularly suited for experimental purposes the 1^+ isotriplet formed by ^{12}B (g.s.), ^{12}C (15.109 MeV), ^{12}N (g.s.) which, by β^- , γ , β^+ emission, respectively, decay to ^{12}C (g.s.) which is a 0^+ isosinglet. The mass difference between ^{12}B (g.s.) (^{12}N (g.s.)) and ^{12}C (g.s.) is ³⁾ 13.881 MeV (16.833 MeV).

The aim of this kind of experiments is to measure the shape factor slopes $a_{\mp}$ for $\beta^{\mp}$ decay which, using CVC, are predicted in terms of $(f\tau_{1/2})^{\mp}$ and Γ_{γ} . In the early sixties, experimental results for these slopes were published by Mayer-Kuckuck and Michel ⁴⁾ and by Lee, Mo and Wu ⁵⁾. There was serious disagreement between the values of $a_{\pm}$ coming from these experiments and only the last one was in good agreement with CVC. It is worth noticing that the values of $(a_- - a_+)$, less prone to experimental errors, were compatible and also in agreement with the measurement of Glass and Peterson ⁶⁾ as well as with the CVC prediction. For many physicists this was accepted as sufficient proof of CVC until Calaprice and Holstein ⁷⁾ reanalyzed the experiment of Ref. 5) and obtained values for $a_{\pm}$ in disagreement with CVC. In an ulterior reanalysis of their experiment, Wu and Lee and Mo ⁸⁾ observed that some effects considered negligible in Ref. 7) were very important and they restored the good agreement between their experimental results and CVC. Upon this unsatisfactory situation a new experimental result has been added ⁹⁾. They have obtained a value of $(a_- - a_+)$ which agrees with CVC with a 10% precision. Nevertheless the individual slopes which are very different from those of Ref. 8) are in disagreement with the theoretical prediction that seems to depend more strongly on what was thought of higher order axial terms ¹⁰⁾. As a summary we can say that the four existing experimental values of $(a_- - a_+)$ are in quite good agreement among themselves and tend to support CVC; nevertheless, the three experimental results for the individual slopes are very different and furthermore it is not clear which is the theoretical value implied by CVC. For these reasons we feel that an independent test of CVC is needed.

The nuclear system so far considered is also very interesting because polarized nuclei of ^{12}B (g.s.) and ^{12}N (g.s.) can be produced with adequate yields as to be able to measure the angular distribution of the outgoing $e^{\mp}$ with respect to the direction of polarization of the initial nucleus. This decay asymmetry can be characterized through a parameter $\alpha_{\mp}$ which is sensitive not only to CVC but also to the existence of second class currents. In the framework of CVC theory and in the absence of second class currents the quantity $(\alpha_- - \alpha_+)$ is easily predicted; the theoretical determination of the individual values $\alpha_{\mp}$ implies the use of a nuclear model. The first measurement of $\alpha_{\mp}$ was carried out by Sugimoto et al. ¹¹⁾; their result for $(\alpha_- - \alpha_+)$ was roughly twice that calculated using CVC and in the absence of second class currents. A contributed experimental paper to the Santa Fe Conference ¹²⁾ pointed out, however, that a measurement of α_- gave a result that was compatible with zero, in disagreement with Ref. 11). Furthermore, Morita et al. ¹³⁾ using these hypotheses, the impulse approximation and realistic nuclear wave functions were able to explain the experimental value of α_+ but it was impossible to get agreement for α_- . They concluded that experimental data of Ref. 11) were in favour of the existence of second class currents. Since then the situation has changed drastically. Lebrun et al. ¹⁴⁾ reported at the Zürich Conference a preliminary value of α_- which is compatible with zero and in agreement with the theoretical analysis of Ref. 13) in the absence of second class currents. Furthermore, in this Conference, some preliminary evidence from a new measurement was given by Sugimoto et al. with a value of α_- compatible with zero, α_+ very similar to their old result, and $(\alpha_- - \alpha_+)$ compatible with CVC and absence of second class currents. In this kind of experiments all the new preliminary results seem to point out towards the desired situation (validity of CVC and absence of second class currents) but precise values of $\alpha_{\mp}$ are still lacking. We would like to mention that now the only clear indication of second class currents comes from an experiment of this type carried out by Calaprice et al. ¹⁵⁾ in ^{19}N . Their results imply the existence of a second class form factor comparable to the weak magnetism term.

Since there are not yet widely accepted values of $a_{\pm}$ and $\alpha_{\pm}$ it is important to have an independent test of CVC. In this paper we present a clean test of CVC that depends on $(f_{\tau\frac{1}{2}})^{-}$, the muon capture rate for

and the average polarization of the outgoing nucleus in this process. Since the nuclei are treated as elementary particles, no problems related with the impulse approximation or with the use of realistic wave functions will appear.

In Section 2 the general equations needed are obtained. In Section 3, a test of CVC is presented. The next section is devoted to PCAC and possible values of the shape factor slope and the asymmetry parameter of the β^- decay of ^{12}B . In the last section, we make some general comments on the $\beta^\pm$ decay problem.

2. - GENERAL EQUATIONS

The β^- decay of ^{12}B (g.s.) to ^{12}C (g.s.) is a $1^+ \rightarrow 0^+$ transition and therefore the nuclear part of this process can be fully described by an invariant vector form factor and three axial vector ones, which in the notation of Galindo and Pascual¹⁶⁾ are, respectively, $F_-^{(11)}(q^2)$ and $A_-^{(1)}(q^2)$, $F_-^{(01)}(q^2)$, $F_-^{(21)}(q^2)$ where q^2 is the squared four-momentum transfer. (The minus sign has been added to denote the form factors associated with the branch $^{12}\text{B} - ^{12}\text{C}$.) We are going to define

$$A_-^{(L)}(q^2) \equiv \nu^L B_-^{(L)}(q^2), \quad F_-^{(eL)}(q^2) \equiv \nu^e G_-^{(eL)}(q^2) \quad (2)$$

where

$$\nu = \frac{1}{2m_1 m_2} \lambda^{1/2}(q^2, m_1^2, m_2^2) \simeq \frac{1}{m_-} (\delta_-^2 - q^2)^{1/2} \simeq \frac{|\vec{q}|}{m_-} \quad (3)$$

being $m_1 = m(^{12}\text{B})$, $m_2 = m(^{12}\text{C}) = M = 1.1174953(31) \times 10^4$ MeV, $m_- \equiv (m_1 + m_2)/2$, $\delta_- \equiv m_2 - m_1 = 13.881$ MeV and λ is the Källen lambda function. These new form factors are smooth functions of q^2 in the range of momentum transfer that we are interested in¹⁶⁾.

To study β decay we are going to neglect the dependence on q^2 of $G_-^{(eL)}$ and $B_-^{(L)}$ and furthermore we will keep terms up to order ν only. This approximation is equivalent to neglecting terms of order $|\vec{q}|^2/m_p^2$, $(|\vec{q}|/R)^2$ in the usual impulse approximation. If the initial nucleus

has polarization λ_1 then a straightforward calculation allows us to write for the energy and angular distribution of the emitted electrons

$$\frac{d^3 \Gamma_-(\lambda_1)}{dE d\Omega} = \frac{G^2}{6 (2\pi)^4 m_-^2} F_-(Z, E) p E (\delta_- - E)^2 [G_-^{(01)}(0)]^2 [1 + \eta_- + \alpha_- E].$$

$$\cdot \left[1 - \lambda_1 (1 + \alpha_- E) \frac{p}{E} P_1(\cos \theta) + (3\lambda_1^2 - 2) \alpha_- E \frac{p^2}{E^2} P_2(\cos \theta) \right] \quad (4)$$

where

$$\begin{aligned} \eta_- &\equiv \frac{\delta_-}{3m_-} \left[\frac{2\sqrt{6} G_-^{(11)}(0)}{G_-^{(01)}(0)} - \frac{2\sqrt{3} B_-^{(11)}(0) - G_-^{(01)}(0)}{G_-^{(01)}(0)} \right] \\ \alpha_- &\equiv \frac{1}{3m_-} \left[\frac{2\sqrt{3} B_-^{(11)}(0) - G_-^{(01)}(0)}{G_-^{(01)}(0)} - \frac{\sqrt{6} G_-^{(111)}(0)}{G_-^{(01)}(0)} \right] \\ \alpha_- &\equiv - \frac{4\sqrt{2}}{\sqrt{3} m_-} \frac{G_-^{(11)}(0)}{G_-^{(01)}(0)} \end{aligned} \quad (5)$$

where $F_-(Z, E)$ is the Fermi function for this decay. This formula coincides with the one of Hwang and Primakoff ¹⁷⁾ if we take into account that our form factors in terms of theirs are :

$$\begin{aligned} G_-^{(01)}(0) &= -m_- 2\sqrt{6} F_A^-(0) \quad , \quad G_-^{(11)}(0) = m_- \frac{2m_-}{m_p} F_M^-(0) \\ B_-^{(11)}(0) &= -m_- \sqrt{2} \left[F_A^-(0) - \frac{m_-}{m_p} F_E^-(0) \right] \end{aligned} \quad (6)$$

Integrating (4) we obtain for the total width

$$\Gamma_- = \frac{G^2 m_e^5}{3 (2\pi)^3 m_-^2} [G_-^{(01)}(0)]^2 f_- \left\{ 1 + \eta_- + \alpha_- m_e \frac{g_-}{f_-} \right\} \quad (7)$$

where

$$f_- \equiv \int_1^{\delta_-/m_e} dx \, x \sqrt{x^2 - 1} \left(\frac{\delta_-}{m_e} - x \right)^2 F_-(Z, m_e x)$$

$$g_- \equiv \int_1^{\delta_-/m_e} dx \, x^2 \sqrt{x^2 - 1} \left(\frac{\delta_-}{m_e} - x \right)^2 F_-(Z, m_e x) \quad (8)$$

If in g_-/f_- , which appears only in a small corrective term, we substitute $F_-(E, m_e x)$ by 1, then $g_-/f_- \simeq \delta_-/2m_e$ and hence

$$\Gamma_- = \frac{G^2 m_e^5}{3 (2\pi)^3 m_-^2} [G_-^{(0)}(0)]^2 f_- \left\{ 1 - \frac{\delta_-}{3m_-} \frac{2\sqrt{3} B_-^{(1)}(0) - G_-^{(0)}(0)}{G_-^{(0)}(0)} \right\} \quad (9)$$

Then from Eqs. (4), (5) and (9) we can obtain the form factors at $q^2 = 0$ in terms of measurable quantities :

$$\frac{G_-^{(0)}(0)}{M} = - \left[\frac{\ln 2}{f_- \tau_{1/2}^-} \frac{24 \pi^3}{G^2 m_e^5} \right]^{1/2} \cdot \left\{ 1 + \frac{1}{2} \delta_- \left(\alpha_- - \frac{1}{4} a_- \right) \right\}$$

$$\frac{G_-^{(1)}(0)}{G_-^{(0)}(0)} = - \frac{\sqrt{3} m_-}{4 \sqrt{2}} a_-$$

$$\frac{B_-^{(1)}(0)}{G_-^{(0)}(0)} = + \frac{1}{2\sqrt{3}} + \frac{\sqrt{3} m_-}{2} \left(\alpha_- - \frac{1}{4} a_- \right) \quad (10)$$

We will use $G = (1.135 \pm 0.001) \times 10^{-11} \text{ MeV}^{-2}$, $f_- = (5.6113 \pm 0.0026) \times 10^5$ ¹⁸⁾, $\tau_{1/2}^- = (21.01 \pm 0.09) \text{ msec.}$ ¹⁸⁾. For the β^+ decay of $^{12}\text{N} (\text{g.s.})$ to $^{12}\text{C} (\text{g.s.})$ we must change the subindices $-$ to $+$ and the sign of the right-hand side of the second equation. Furthermore $m_+ = M + \delta_+/2$, $\delta_+ = 16.883 \text{ MeV}$, $f_+ = (1.1327 \pm 0.0017) \times 10^6$ ¹⁸⁾, $\tau_{1/2}^+ = (11.61 \pm 0.07) \text{ msec.}$ ¹⁸⁾.

More information on these form factors is obtained if we consider the muon capture process (1). From general formulae given in Ref. 16), it is immediate to obtain the muon capture rate

$$\Gamma = \frac{G^2}{32 \pi^2} (Z \alpha m_\mu')^3 M \frac{[(M + m_\mu)^2 - (M + \delta_-)^2]^2}{(M + m_\mu)^3} C_4 |T|^2$$

$$|T|^2 = M^{-2} [X_4^2 + Y_4^2] \quad (11)$$

where $Z=6$, m_μ' is the reduced muon mass, $C_1 = (Z_{\text{eff}}/Z)^4$ and we will adopt for it the value $C_1 = (0.856 \pm 0.007)^{19}$. The quantities X_1 and Y_1 are defined by

$$\begin{aligned} X_1 &\equiv A_-^{(1)}(q^2) - \frac{1}{\sqrt{3}} F_-^{(01)}(q^2) + \sqrt{\frac{2}{3}} F_-^{(21)}(q^2) \\ Y_1 &\equiv -\sqrt{\frac{2}{3}} F_-^{(01)}(q^2) + F_-^{(11)}(q^2) - \frac{1}{\sqrt{3}} F_-^{(21)}(q^2) \end{aligned} \quad (12)$$

where $q^2 = -m_\mu(Mm_\mu - m_{\delta_-})(M+m_\mu)^{-1}$. It is easy to check that these quantities are proportional, respectively, to the helicity amplitudes M_0 and M_{-1} ²⁰. Also from Ref. 16) it is easy to prove that the asymmetry parameter α of the angular distribution of the recoiling nucleus is given by

$$\alpha = \frac{X_1^2 - Y_1^2}{X_1^2 + Y_1^2} \quad (13)$$

Then it is clear that if Γ and α are measured we can obtain values for X_1 and Y_1 solving Eqs. (11) and (14).

The value of the muon capture rate has been measured many times²¹ and we will take as best value the weighted average of these measurements, except (ii) and (iii) which are too high. We obtain $\Gamma = (6.29 \pm 0.16) \times 10^3 \text{ sec}^{-1}$. The quantity α has never been measured but there is an experimental value for the average polarization P , which is related to α through the equations²⁰)

$$\begin{aligned} \alpha &= 1 + 2 P_L \\ 9 P_L^2 + 2(3P + 4) P_L + 9P^2 &= 0 \end{aligned} \quad (14)$$

P_L being the longitudinal polarization.

Other measured quantities in this system are the width of the decay $^{12}\text{C}(15.109) \rightarrow ^{12}\text{C}(\text{g.s.}) + \gamma$ and the differential cross-section for the inelastic electron scattering: $e^- + ^{12}\text{C}(\text{g.s.}) \rightarrow ^{12}\text{C}(15.109) + e^-$. All these quantities can be calculated in terms of a unique vector form factor $F_{\text{E.M.}}^{(11)}(q^2)$ ¹⁶). The decay width is given by

$$\Gamma_Y = \frac{\alpha m_2}{6 m_1^2} \nu^3 \left[\frac{1}{\sqrt{2}} G_{E.M.}^{(11)}(0) \right]^2 \quad (15)$$

where ν is the quantity defined in (3) for $q^2 = 0$. m_1 and m_2 are, respectively, the initial and final nuclear masses. We choose the normalization in such a way that if CVC is exact then $F_{E.M.}^{(11)}(q^2) = F_-^{(11)}(q^2)$.

From the experimental result $\Gamma_Y = (37.0 \pm 1.1) \text{ eV}^2$ we obtain

$$G_{E.M.}^{(11)}(0) = (47.05 \pm 0.70) M \quad (16)$$

The variation of $G_{E.M.}^{(11)}(q^2)$ versus q^2 coincides with that of $B(M1, q^2)$ of Ref. 22); then using Eq. (11c) of that paper we obtain

$$\frac{G_{E.M.}^{(11)}(q^2)}{G_{E.M.}^{(11)}(0)} = (0.752 \pm 0.044) \quad (17)$$

for q^2 corresponding to muon capture.

3. - A TEST OF CVC

We are going to present a test of CVC based on the well-established experimental value of $f_- \tau_{1/2}^-$ for the β^- decay of ^{12}B and the capture rate of process (1). We will need also the experimental value of the average polarization of the recoiling nucleus in (1).

From expression (10) and the experimental value of $f_- \tau_{1/2}^-$ we obtain

$$G_-^{(01)}(0) = - (2.5330 \pm 0.0082) \left[1 + 0.0694 \left(\beta_- - \frac{1}{4} b_- \right) \right] M \quad (18)$$

where $\beta_- = \alpha_- \times 10^{-2} \text{ MeV}$ and $b_- = a_- \times 10^{-2} \text{ MeV}$. Furthermore from (11) and the experimental capture rate

$$X_1^2 + Y_1^2 = (3.72 \pm 0.13) M^2 \quad (19)$$

The value of the average polarization P has been measured by Possoz et al. ²³⁾. They measured $P = 0.452 \pm 0.042$, but this number must be corrected due to the presence in the final state of bound states of ^{12}B other than the ground state. Using a simple particle-hole model the average polarization for process (1) turns out to be $P = 0.537 \pm 0.049$. From this value of P and solving Eq. (14) we obtain as possible values of the asymmetry parameter $\alpha = -(0.880^{+0.056}_{-0.087})$ and $\alpha = +(0.39^{+0.12}_{-0.15})$. We will take the first one since the impulse approximation, with any sensible nuclear model, predicts that α must be large and negative. Using (13) and (19) we obtain for a given polarization P :

$$X_1 = (0.643 \pm 0.044) M \left[5 - 3P - 2 \sqrt{-18P^2 + 6P + 4} \right]^{1/2}$$

$$Y_1 = (0.643 \pm 0.044) M \left[4 + 3P + 2 \sqrt{-18P^2 + 6P + 4} \right]^{1/2} \quad (20)$$

where the signs have been chosen compatible with the impulse approximation.

Now we are going to use this value of Y_1 and $G_-^{(01)}(0)$, found before, to determine $F_-^{(11)}(q^2)$. To this end we are going to assume that

$$\frac{F_-^{(01)}(q^2) + \frac{1}{12} F_-^{(21)}(q^2)}{F_-^{(01)}(0)} = \frac{G_-^{(11)}(q^2)}{G_-^{(11)}(0)} \quad (21)$$

That this hypothesis must be very good is discussed in the Appendix.

Using (21) as well as (12) we obtain

$$F_-^{(11)}(q^2) = Y_1 + \sqrt{\frac{2}{3}} \frac{G_-^{(11)}(q^2)}{G_-^{(11)}(0)} G_-^{(01)}(0) \quad (22)$$

If furthermore we assume that $G_{-}^{(11)}(q^2)/G_{-}^{(11)}(0)$ varies versus q^2 as in the electromagnetic case (17) we are able to calculate $F_{-}^{(11)}(q^2)$. In Fig. 1 we present $R \equiv F_{-}^{(11)}(q^2)/F_{-}^{(11)}(q^2)_{E.M.}$ versus P for $(\beta_{-} - \frac{1}{4}b_{-}) = 0$. Notice that

$$R = R \Big|_{\beta_{-} - \frac{1}{4}b_{-} = 0} - 0.37 (\beta_{-} - \frac{1}{4}b_{-}) \quad (23)$$

This is a rather small correction, compared with the errors, since in any realistic nuclear model ^{10),13)} you expect that $\beta_{-} - \frac{1}{4}b_{-} \simeq -0.15$. Then this corrective term would increase slightly the value of R . In Fig. 1 we have drawn a vertical strip corresponding to the allowed values of P when the measured ones have been corrected using a particle-hole nuclear model. Then we can conclude that

$$R = 1.09 \pm 0.25 \quad (24)$$

in complete agreement with CVC. Recently, some doubts have been raised ²⁴⁾ on the way to correct the measured value of P . Using some realistic nuclear wave functions the correction needed is very small and the final value for the average polarization turns out to be $P = 0.445 \pm 0.042$ which is barely compatible with CVC. It is clear that this goes against the canonical expectations since we would prefer a slightly higher value of the average polarization $P \sim 0.57$. Notice that this is precisely the value of Hwang and Primakoff ¹⁷⁾ under their hypothesis C : CVC and absence of second class currents, plus some information obtained through the impulse approximation.

Before we finish this section we must point out that a somewhat similar approach to check CVC has been carried out in the framework of the impulse approximation ^{23),25)} with similar results.

Finally, we should stress the fact that a good measurement of Γ will considerably reduce the errors in R and then a clean test of CVC will be obtained.

4. - LET US ASSUME PCAC

We are going to see that the value of X_1 given in (21), which is obtained from muon capture data, will allow us, when PCAC is used, to draw some conclusions on possible values of $(\beta_- - \frac{1}{4}b_-)$.

If we assume that the divergence of the axial current is dominated by the pion pole, then the PCAC relation can be rewritten as

$$\frac{1}{F_-^{(0)}(0)} \left[F_-^{(0)}(q^2) - \sqrt{2} F_-^{(2)}(q^2) + \frac{\delta_-}{m_\pi v} A_-^{(1)}(q^2) \right] = \frac{m_\pi^2}{m_\pi^2 - q^2} \frac{G_-^{(11)}(q^2)}{G_-^{(11)}(0)} \quad (25)$$

where the numerator of the left-hand side is proportional to the divergence of the axial current ¹⁶⁾. Using (25) and the milder assumption (21) we can write the quantity X_1 defined in (12) as

$$X_1 = \left[1 + \frac{1}{\sqrt{3}} \frac{\delta_-}{m_\pi v} \right] A_-^{(1)}(q^2) - \frac{1}{\sqrt{3}} \frac{m_\pi^2}{m_\pi^2 - q^2} \frac{G_-^{(11)}(q^2)}{G_-^{(11)}(0)} G_-^{(0)}(0) \quad (26)$$

If we assume also that

$$\frac{B_-^{(1)}(q^2)}{B_-^{(1)}(0)} = \frac{G_{\text{E.M.}}^{(11)}(q^2)}{G_{\text{E.M.}}^{(11)}(0)} \quad (27)$$

we obtain immediately, using (10), (18) and (20), $(\beta_- - \frac{1}{4}b_-)$ versus P and this is represented in Fig. 2. To have an idea of how PCAC affects the value of $(\beta_- - \frac{1}{4}b_-)$ in Fig. 2 we have drawn a shaded region corresponding to multiplying the right-hand side of Eq. (25) by $\lambda \equiv (1.0 \pm 0.2)$ for the q^2 corresponding to muon capture. The lower limit of this zone corresponds, through the impulse approximation, to values of g_P higher than the ones obtained from the Goldberger-Treiman relation. In the impulse approximation and using a realistic nuclear model ¹³⁾ the relation between g_P and λ is $g_P \simeq 28.6 - 22.1 \lambda$. In Fig. 2 we have drawn also the region of allowed values of P . From all that it is clear that also here we would prefer a somewhat larger value of P in order to obtain for $(\beta_- - \frac{1}{4}b_-)$ a small but negative value. With the present value of P we can reach the region of values of $(\beta_- - \frac{1}{4}b_-)$ favoured by the experimental results as well as the theoretical calculations if we use quite small values of λ (i.e., values of g_P as large as $g_P \simeq 15$) in agreement with Leroy and Palffy ²⁶⁾.

Notice that the content of this section rests not only in the PCAC hypothesis but also in the validity of the last equation of (10) which has been obtained under assumptions which are equivalent in the impulse approximation to neglect terms of order $|\vec{q}|^2/m_p^2$ and $(|\vec{q}|R)^2$. Important effects due to the neglected terms in the last equation of (10) can modify our conclusions. It would be interesting to calculate with a realistic nuclear wave function and in the considered approximation the values of $f\pi$, α_- , a_- , Γ and P in order to check the internal consistency of these approximations.

5. - OTHER COMMENTS:

Before finishing this paper we would like to make some remarks on possible values of $b_{\pm}$. If we accept that $G_{-}^{(11)}(0) = G_{+}^{(11)}(0)$ which is a direct consequence of the hypothesis that 12_B^{-} and 12_N^{+} are in the same isotriplet and that the weak current is an isovector, we obtain immediately, from (10) and the equivalent equations for the β^{+} decay, that $b_{-} = -(0.9471 \pm 0.0074) b_{+}$. From all experimental results only those of Ref. 5) are in good agreement with this prediction since they obtain $b_{-} = 0.51 \pm 0.10$ and $b_{+} = -0.55 \pm 0.09$. Obviously this relation can be modified by terms of order $|\vec{q}|^2/m_p^2$ and $(|\vec{q}|R)^2$ that we have not considered.

As we have pointed out in the Introduction the values of $(b_{-} - b_{+})$ from the different experiments are in good agreement. The values of Refs. 4), 5), 6) and 9) are, respectively, 1.22 ± 0.12 , 1.06 ± 0.13 , 1.62 ± 0.28 and 0.98 ± 0.09 . If we accept for this difference $b_{-} - b_{+} = 1.1 \pm 0.2$ and the equality of $G_{-}^{(11)}(0)$ and $G_{+}^{(11)}(0)$ then we obtain

$$\frac{G_{+}^{(11)}(0)}{G_{E.M.}^{(11)}(0)} = + (0.99 \pm 0.19) \quad (28)$$

in good agreement with CVC. The corresponding values of $b_{\mp}$ are $b_{-} = 0.535 \pm 0.097$, $b_{+} = -(0.57 \pm 0.11)$.

Furthermore if you accept CVC and the absence of second class currents you expect that $B_{-}^{(1)}(0) \simeq B_{+}^{(1)}(0)$ and this implies through Eqs. (10) that

$$\beta_- - \beta_+ = \frac{1}{4} (b_- - b_+) \approx 0.27 \quad (29)$$

This was in complete disagreement with the old value of Sugimoto et al.¹¹⁾ $\beta_- - \beta_+ = 0.52 \pm 0.09$. At the Zürich Conference, Lebrun et al.¹⁴⁾ reported a preliminary value of $\beta_- = 0.00 \pm 0.05$. Also Sugimoto et al. have repeated their experiment with a different technique and have obtained as preliminary values $\beta_- = 0.00 \pm 0.08$, $\beta_+ = -0.27 \pm 0.08$, in amazingly good agreement with Eq. (29).

From all that it is clear that it is very important to clarify theoretically and experimentally all problems that beset the determination of $a_{\mp}$ and $\alpha_{\mp}$. Meanwhile, we have presented a test of CVC which is much easier to interpret. To improve it considerably will require a new precise measurement of the muon capture rate on ^{12}C and to resolve the controversy about the "true" value of the average polarization of the ground state of ^{12}B .

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APPENDIX

We give here the expression of our form factors in terms of those of the nucleon through the use of the impulse approximation ²⁷⁾

$$F_-^{(11)}(q^2) = -g_V(q^2) \left[\frac{i \vec{\sigma} \cdot \vec{q}}{m_p} \right]^{11} + \frac{m_- v}{2 m_p} [g_V(q^2) + g_M(q^2)] \sqrt{\frac{2}{3}} ([\sigma]^{10} - \frac{1}{\sqrt{2}} [\sigma]^{12})$$

$$A_-^{(1)}(q^2) = g_A(q^2) \left[\frac{i \vec{\sigma} \cdot \vec{q}}{m_p} \right]^L + \frac{m_- v}{2 m_p} g_A(q^2) \frac{1}{\sqrt{3}} ([\sigma]^{10} + \sqrt{2} [\sigma]^{12}) \quad (A.1)$$

$$F_-^{(01)}(q^2) = -g_A(q^2) [\sigma]^{10} + \frac{m_-^2 v^2}{6 m_p m_\mu} g_P(q^2) ([\sigma]^{10} + \sqrt{2} [\sigma]^{12})$$

$$F_-^{(21)}(q^2) = +g_A(q^2) [\sigma]^{12} - \frac{m_-^2 v^2}{6 m_p m_\mu} g_P(q^2) \sqrt{2} ([\sigma]^{10} + \sqrt{2} [\sigma]^{12})$$

where the nucleon form factors are those of Mukhopadhyay ²⁸⁾. We have neglected second class currents. If maintained, and if a nucleon tensor form factor was existing, only the expression for $A_-^{(1)}(q^2)$ must be modified, substituting in the last term of the right-hand side $g_A(q^2)$ by $g_A(q^2) + g_T(q^2)$.

From here

$$F_-^{(01)}(q^2) + \frac{1}{\sqrt{2}} F_-^{(21)}(q^2) = -g_A(q^2) ([\sigma]^{10} - \frac{1}{\sqrt{2}} [\sigma]^{12}) \quad (A.2)$$

In any realistic nuclear model the nuclear matrix element $[i \vec{\sigma} \cdot \vec{q} / m_p]^{11}$ is negligible ²⁸⁾ and therefore the dependence on q^2 of (A.2) and $G_-^{11}(q^2)$ is exactly the same if we neglect the difference in the variation of $g_A(q^2)$ and $g_V(q^2) + g_M(q^2)$ versus q^2 .

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FIGURE CAPTIONS

Figure 1 $F_{-}^{(11)}(q^2)/F_{E.M.}^{(11)}(q^2)$ versus the average polarization P . The shaded regions are the errors due to the uncertainty in the values of Γ and $(f\tau_{\frac{1}{2}})^{-}$. The experimental value of P is also shown.

Figure 2 $(\beta_{-} - \frac{1}{4}b_{-})$ versus the average polarization P . The shaded region represents the errors coming for a given violation of the PCAC relation as explained in the text. The experimental value of P is also shown.

FIG 1

FIG 2