Weak vector coupling from neutron β-decay and possible indications of right-handed currents

A. P. Serebrov and N. V. Romanenko
St. Petersburg Institute of Nuclear Physics, 188350, Gatchina, St. Petersburg District

(Submitted 2 March 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **55**, No. 9, 490–494 (10 May 1992)

The results of determination of the weak interaction coupling constants (G'_V and G'_A), obtained from neutron lifetime and electron-spin asymmetry of neutron β-decay, are presented. The possible reasons for the discrepancy of G'_V values are discussed.

The precise measurements of neutron β-decay make it possible to determine the vector and axial-vector constants of weak interaction. These constants are determined from experimental data for the neutron lifetime (τ_n) and the asymmetry of neutron β-decay (A_n). However, because of the low accuracy of the neutron experiment, this method for a long time was not competitive with the well-known method for determination of G_V from superallowed 0^+–0^+ nuclear transitions. The accuracy of the neutron lifetime determination and of the β-decay asymmetry has recently been improved considerably.[1–6] Using the average value for the neutron lifetime $\tau_n = 887.0 \pm 1.6$ s and the average value for the electron-spin polarization asymmetry of β-decay $A_n^0 = -0.1126 \pm 0.0011$, one can obtain the results for the vector and axial-vector constants ${}^nG'_V$ and ${}^nG'_A$

$$ {}^nG'_V = G_V(1+\Delta_\beta)^{\frac{1}{2}} = (1.1584 \pm 0.0024) \times 10^{-5}\ \text{GeV}^{-2}(\hbar c)^3, \tag{1} $$

$$ {}^nG'_A = G_A(1+\Delta_\beta)^{\frac{1}{2}} = (-1.4561 \pm 0.0014) \times 10^{-5}\ \text{GeV}^{-2}(\hbar c)^3, \tag{2} $$

where Δ_β is the inner radiative correction for the process $n \to p + e^- + \tilde{\nu}_c$ in the standard electroweak theory.

The values of the weak coupling constant as determined from β^+-decays in superallowed 0^+–0^+ transitions have been presented in several papers. These values differ from each other by the calculation of the nuclear structure corrections: ${}^{00}G'_V = (1.14809 \pm 0.00045) \times 10^{-5}$ (Ref. 7), ${}^{00}G'_V = (1.14939 \pm 0.00065) \times 10^{-5}$ (Ref. 8), ${}^{00}G'_V = (1.1510 \pm 0.0005) \times 10^{-5}$ (Ref. 9), ${}^{00}G'_V = (1.1516 \pm 0.0005) \times 10^{-5}$ (Ref. 9). One can see a systematic increase of G'_V with time. It seems that the last value takes into account the nuclear structure effects very accurately.

The vector coupling can be extracted from decays of strange particles using the G_μ value and the unitarity of the Kobayashi–Maskawa matrix:[10] ${}^{un}G_V(1+\Delta_\beta)^{1/2} = G_\mu(1+\Delta_\beta-\Delta_\mu)^{1/2}(1-|V_{us}|^2-|V_{ub}|^2)^{1/2} = (1.1514 \pm 0.0015) \times 10^{-5}$.

In addition, a great interest has arisen in the decay asymmetry and lifetime data of ^{19}Ne reported recently in Ref. 11. The positronic decay of ^{19}Ne is actually the β^+-decay of a proton in the nucleus. The asymmetry and the lifetime measurements of ^{19}Ne[$A_{\rm Ne} = -0.03669 \pm 0.00083$, $(F\tau)_{\rm Ne} = 1717.6 \pm 3.7$ s] give here: $^{\rm Ne}G'_V = (1.1478 \pm 0.0016) \times 10^{-5}$ and $^{\rm Ne}G'_A = (-1.0664 \pm 0.0013) \times 10^{-5}$.

All the data given above are shown in Fig. 1. One can see a discrepancy between the G'_V value from the neutron β-decay and the other G'_V values. The largest contradiction is observed between the G'_V values from the neutron and ^{19}Ne ($^nG'_V - {}^{\rm Ne}G'_V = 3.7\sigma$). This contradiction remains at the 2.1σ level even if the results on the asymmetry,[2] which are the main source of this discrepancy, are excluded.

It seems possible to follow the different directions in the discussion of this contradiction: 1) It may result from the systematic lowering of the experimentally measured absolute value of decay asymmetry and/or the neutron lifetime, 2) it may be connected with the incomplete calculation of the radiative corrections, 3) it may be due to the presence of right-handed currents in the nucleon β-decay. The latter alternative can

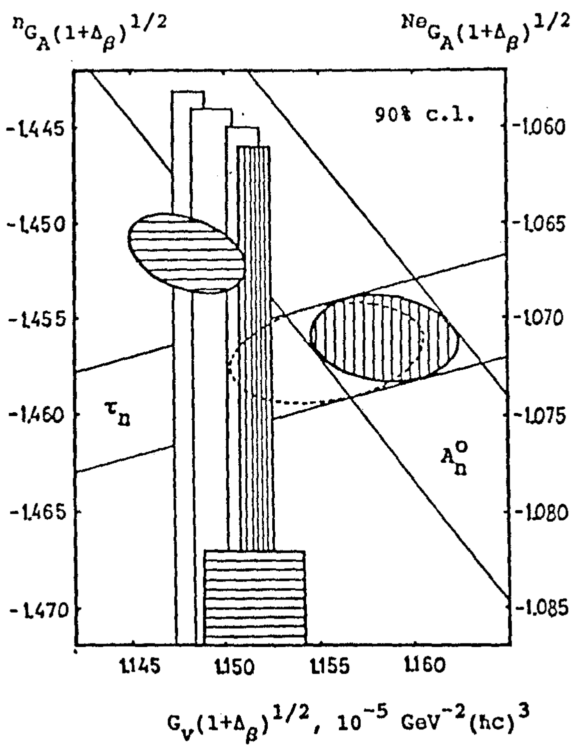

FIG. 1. Determination of the weak couplings from different experimental data (90% c.l.): a) from the decay asymmetry A_n and the neutron lifetime τ_n—the right ellipse (the dotted-line ellipse is the same without the data from Ref. 2); b) from the decay asymmetry of ^{19}Ne ($A_{\rm Ne}$) and ^{19}Ne lifetime ($\tau_{\rm Ne}$)—the left ellipse; c) from the $F\tau$ data for 0^+–0^+ transitions—the higher bargraphs; d) from the decays of strange particles, G_μ, and the unitarity of the Kobayashi–Maskawa matrix—the lower bargraphs.

explain the largest discrepancy between the neutron and ^{19}Ne data. Further, it will be shown that the choice between these options can be made by performing new, rather precise experiments: measurement of the ratio $(A-B)/(A+B)=\lambda_{AB}$ [which implies simultaneous measurement of the electron-spin (A) and the neutrino-spin polarization asymmetry (B), without exact determination of the neutron beam polarization] and measurement of the B value with the precise determination of this polarization.

Let us discuss, on a very preliminary basis, the third option, i.e., the existence of right-handed currents in the nucleon β-decay, which was considered in different aspects in Refs. 1, 11, and 12. Taking into account the right-handed currents,[13] we can write the electron-spin asymmetry as

$$A_n = -2\frac{\lambda_n^2(1-y^2)+\lambda_n(1-xy)}{(1+x^2)+3\lambda_n^2(1+y^2)}, \tag{3}$$

and the ratio of the lifetimes as

$$\frac{(F\tau)^{00}}{(F\tau)^n} = \frac{1}{2}\Big(1+3\lambda_n^2\frac{1+y^2}{1+x^2}\Big) \equiv \frac{1}{2}(1+3\lambda_\tau^2), \tag{4}$$

$$(\lambda_n \equiv {}^nG_A'/{}^nG_V').$$

This leads to the connection between the parameters δ and ζ of the model (in the quadratic approximation):

$$A_n + 2\frac{\lambda_\tau^2+\lambda_\tau}{1+3\lambda_\tau^2} = \frac{4(\lambda_\tau^2+\lambda_\tau)}{1+3\lambda_\tau^2}\delta^2 + \frac{8\lambda_\tau^2}{1+3\lambda_\tau^2}\delta\zeta + \frac{4\lambda_\tau^2}{1+3\lambda_\tau^2}\zeta^2. \tag{5}$$

Here $x=\delta-\zeta$, $y=\delta+\zeta$, δ is the ratio of the squared masses M_1^2 and M_2^2 (for the mass eigenstates $W_1 = W_L\cos\zeta - W_R\sin\zeta$; $W_2 = W_R\cos\zeta + W_L\sin\zeta$), and ζ is the mixing angle for W_L, W_R. The analogous equation can be written for ^{19}Ne. Adding and subtracting Eq. (5) for neutron and neon, one can find the restrictions on the δ and ζ parameters. The allowed values of δ and ζ are shown in Fig. 2. The neutron data, together with the most precise ^{19}Ne data, play the crucial role, while the 0^+–0^+ transitions are of minor importance. It is worth mentioning that by introducing the right-handed currents one can explain the different signs of the deviations of ${}^nG_V'$ and ${}^{Ne}G_V'$ from ${}^{00}G_V'$. The region of restrictions in Fig. 2, marked by the dotted line, corresponds to the case where the data for the asymmetry A_n of Ref. 2 are excluded. One can see that even without these data the contradiction for the limits from the μ^+-decay[14] is not removed. This discrepancy between the muon decay and the nucleon decay is a serious obstacle in the explanation of the contradiction of the right-handed currents discussed above. We note that the W_R in the analysis can be simulated by the incorrect account of the radiative corrections.

These possibilities can be distinguished on the basis of an analysis of the expressions for $F\tau$ and the decay asymmetry. Taking into account the contribution of the right-handed currents and the radiative corrections, with the mixing angle $\zeta=0$, we can write the following expressions (the right-hand side of the equations given below

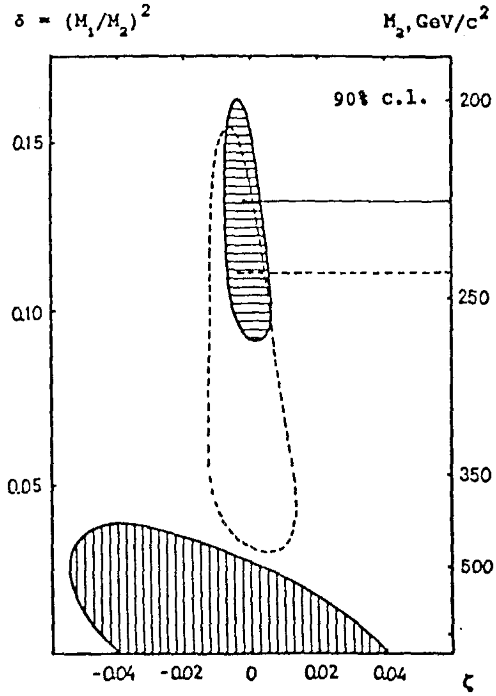

FIG. 2. The region of restrictions for the left-right model parameters δ and ζ from different experimental data (90% c.l.): a) from β^--decay of neutron and β^+-decay of ^{19}Ne—horizontal shaded region, the most probable value $M_{W_R} = 220$ GeV/c^2 (the region shown by the dotted line—the same without data from Ref. 2), the most probable value $M_{W_R} = 240$ GeV/c^2, b) from the μ^+-decay data—the vertical shaded region, $M_{W_R} > 432$ GeV/c^2.

correspond to the leading order in $\delta = M_L^2/M_R^2$):

$$\frac{(F\tau)^{00}}{(F\tau)^n} = \frac{1}{2}\left(1 + 3\lambda_n^2\frac{1+y^2}{1+x^2}\right)\frac{1+\Delta_\beta^n}{1+\Delta_\beta^{00}} \approx \frac{1}{2}(1+3\lambda_n^2)\frac{1+\Delta_\beta^n}{1+\Delta_\beta^{00}}, \tag{6}$$

$$A_0 = -2\frac{\lambda_n^2(1-y^2)+\lambda_n(1-xy)}{(1+x^2)+3\lambda_n^2(1+y^2)} \approx -2(1-2\delta^2)\frac{\lambda_n^2+\lambda_n}{1+3\lambda_n^2}, \tag{7}$$

$$B_0 = 2\frac{\lambda_n^2(1-y^2)-\lambda_n(1-xy)}{(1+x^2)+3\lambda_n^2(1+y^2)} \approx 2(1-2\delta^2)\frac{\lambda_n^2-\lambda_n}{1+3\lambda_n^2}, \tag{8}$$

$$\frac{A_0 - B_0}{A_0 + B_0} = \lambda_n\frac{1-y^2}{1-xy} \approx \lambda_n. \tag{9}$$

Here Δ_β^n and Δ_β^{00} are the uncalculated radiative corrections, and A_0 and B_0 are the experimental values of the electron-spin and neutrino-spin asymmetry, which were corrected by removing the recoil and weak-magnetism effects. The radiative corrections are omitted in Eqs. (7)–(9) since they are negligible in comparison with the experimental accuracy. Since the quantity B_0 is the measured value of the neutrino-spin asymmetry, it equals to $2(\lambda_n^2 - \lambda_n)/(1+3\lambda_n^2)$ in the absence of the right-handed current. When the right-handed currents are present, we can construct the quantity $\lambda_{AB} = A_0 - B_0/A_0 + B_0$, which coincides with λ_n if $\zeta = 0$. The value $B_{AB} \equiv 2(\lambda_{AB}^2 - \lambda_{AB})/(1+3\lambda_{AB}^2)$ will then differ from B_0 only because of the existence of the right-handed currents:

$$\frac{B_{AB}}{B_0} - 1 = 2\delta^2 + 4\frac{3\lambda_{AB}^2 - 1}{3\lambda_{AB}^2 + 1}\delta\zeta + 2\frac{3\lambda_{AB}^2 - 1}{3\lambda_{AB}^2 + 1}\zeta^2. \tag{10}$$

The relationship between the parameters δ and ζ in Eq. (10) is shown schematically in Fig. 3 for different values of the deviation parameter $[(B_{AB}/B_0) - 1]$. The use of the quantities A_0 and B_0 eliminates the need to take exact account of the radiative corrections. As one can see from Fig. 3, to confirm (or reject) the presence of W_R, one should measure B with the accuracy of about 0.3–0.5%. This can be done by using the special method for measuring the neutron beam polarization.[15,16] The use of the quantities A and λ_{AB} is less attractive since it requires highly precise measurements. In addition, the role of radiative corrections for A may have an appreciable effect, while for quantities B and $(A-B)/(A+B)$ this effect is much smaller (since $A \approx 0.1\ B$).

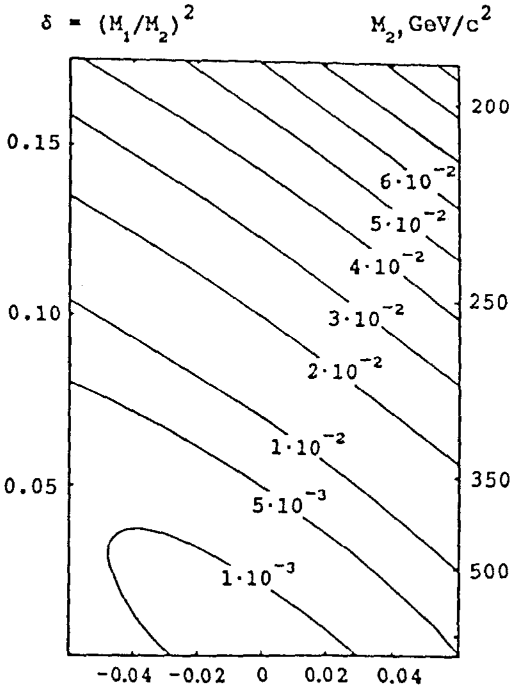

FIG. 3. The correlation between δ and ζ for different values of the deviation parameter $[(B_{AB}/B_0) - 1]$.

Thus, the correct analysis for the right-handed currents needs the comparison of the results obtained from the measurements of B and $(A-B)/(A+B)$, instead of A and $(F\tau)^{00}/(F\tau)^n$, as was the case before. To complete the analysis, one can evaluate the uncalculated radiative corrections by measuring the quantities $(F\tau)^{00}$, $(F\tau)^n$, and λ_{AB}:

$$\Delta_\beta^n - \Delta_\beta^{00} = \frac{(F\tau)^{00}}{(F\tau)^n}\frac{2}{1+3\lambda_{AB}^2} - 1. \tag{11}$$

Thus, at present the most important goal is to measure with higher accuracy the ratio $\lambda_{AB} = A_0 - B_0/A_0 + B_0$ and the value of B. This will make it possible to choose between the three discussed possibilities of the source of the discrepancy between ${}^nG'_V$, ${}^{00}G'_V$, and ${}^{Ne}G'_V$. For example, the option of the right-handed currents is excluded if $B_0 = B_{AB}$, while the possibility of additional radiative corrections is excluded if $\lambda_{AB} = \lambda_\tau$. A more sophisticated analysis will reveal the possible systematic errors or random deviations in the former experiments.

We note in conclusion that if $[(B_{AB}/B_0) - 1] \approx 3\times 10^{-2}$ (so that the region of mass values for W_R in Fig. 2 is confirmed), then the contradiction involving the μ-decay restrictions can be reconciled by assuming that the right-handed neutrinos have Majorana masses, and that the following relations are valid:

$$m_{\nu_\mu^R} > m_\mu - m_e - m_{\nu_e^R},$$

$$m_{\nu_e^R} < m_n - m_p - m_e.$$

The decay via W_R will then be forbidden for the muon and allowed for the neutron.

We wish to thank A. A. Anselm for useful discussions.

[1]V. P. Alfimenkov *et al.*, JETP Lett. **52**, 344 (1990).
[2]B. G. Erozolimsky *et al.*, Yad. Fiz. **52**, 1583 (1990) [Sov. J. Nucl. Phys. **52**, 99 (1990)].
[3]W. Mampe *et al.*, Phys. Rev. Lett. **63**, 593 (1989).
[4]J. Byrne *et al.*, Phys. Rev. **D65**, 289 (1990).
[5]V. I. Morozov, in: Proc. of the Intern. School "Electroweak Interactions Physics At Low Energies" (LEWI'90)/JINR, Dubna, 1991, p. 346.
[6]P. Bopp *et al.*, Phys. Rev. Lett. **56**, 919 (1986).
[7]K. R. Schubert, in *Weak and Electromagnetic Interactions in Nuclei,* Proc. of Intern. Symp./Heidelberg, 1986.
[8]J. C. Hardy *et al.*, Nucl. Phys. A **509**, 429 (1990).
[9]D. H. Wilkinson, Nucl. Phys. **A511**, 301 (1990).
[10]D. Dubbers *et al.*, Europhys. Lett. **11**, 195 (1990).
[11]A. S. Carnoy *et al.*, UCN/IPN Preprint, October 24, 1991. Institut de Physique Nucleaire, Universite Catholique de Louvain, Belgium.
[12]Yu. V. Gaponov *et al.*, Preprint IAE-5032/2, Moscow, 1990.
[13]B. R. Holstein and S. B. Treiman, Phys. Rev. **D16**, 2369 (1977).
[14]A. Jodidio *et al.*, Phys. Rev. **D34**, 1967 (1986).
[15]H. Nastoll *et al.*, Nucl. Instr. Meth. **A306**, 65 (1991).
[16]A. P. Serebrov, Preprint PNPI (in press), SPb., 1992.

Translated by the authors