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Constraints on left-right-symmetric models from neutron decay

A.-S. Carnoy and J. Deutsch
Institut de Physique Nucleaire, Université Catholique de Louvain,
B-1348 Louvain-La-Neuve, Brabant, Belgium

Barry R. Holstein
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

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The implications for left-right-symmetric models of recent neutron-β-decay asymmetry and lifetime measurements are analyzed. The significance of forthcoming high-precision lifetime measurements is stressed.

As is well known, the left-handed nature of the low-energy weak interaction has no fundamental justification and thus left-right-symmetric extensions have been proposed in which the near-maximal parity violation of the standard $SU(2)_L \otimes U(1)$ model is due to spontaneous symmetry breaking of a larger $SU(2)_L \otimes SU(2)_R \otimes U(1)$ gauge group.[1] In such models, the physical (i.e., mass-eigenstate) gauge bosons W_1 and W_2 are linear combinations, with some mixing angle ζ, of the weak eigenstates W_L and W_R which couple to left- and right-handed currents, respectively. Because of spontaneous symmetry breakdown the squared mass ratio of the physical gauge bosons

$$\delta = \left[\frac{M_1}{M_2} \right]^2$$

acquires a nonvanishing and empirically small value. The precise size of the mass ratio δ and the mixing angle ζ must be determined experimentally.

Originally various leptonic and semileptonic processes were analyzed in order to either observe nonvanishing values of (ζ,δ) or set upper limits to these parameters.[2,3] In addition, nonleptonic transitions, which require the somewhat model-dependent evaluation of the weak decay amplitudes, were investigated.[4] Finally, generalizations of the initial "manifest" left-right-symmetric models, introducing additional parameters, were studied.[5] For such cases, the theoretically based nonleptonic strictures are no longer valid and limits must be empirically based.

On the experimental side, the decay asymmetry of polarized muons provides rather stringent upper bounds at about the 5×10^{-2} level (cf. Fig. 1) for both δ and ζ.[6] It has been noted, however, that at this level of precision the method runs into limitations due to muon depolarization.[7]

β-decay experiments are subject to different systematics and—if pursued to sufficient precision—yield complementary constraints in δ,ζ space both in the "manifest" left-right-symmetric model[2,3] and in its extensions.[5] For the purpose of such investigations, any manifestation of parity violation is suitable. β-ray longitudinal polarization (both absolute and relative in Fermi to Gamow-Teller transitions) has been studied[8] and is currently under scrutiny at various laboratories.[9] The limits obtained thereby are indicated in Figs. 1 and 2. The β asymmetry from polarized ^{19}Ne (Refs. 10 and 11) has also proved to offer a powerful constraint.[3] [The more precise results of Ref. 11 are generally used in the recent evaluations to set upper limits to the relevant parameters (cf. Figs. 1 and 2).] It should be noted, however, that in a recent experiment on ^{35}Ar, results obtained with atomic beams, such as the one reported in Refs. 10 and 11, were found to be prone to systematic errors.[12]

With the advent of polarized ultracold neutron beams,[13] high-precision neutron-β-decay asymmetry measurements became possible and led to the result[14]

$$A = -0.1146 \pm 0.0019 . \tag{1}$$

Consequently it seems worthwhile to examine the possible

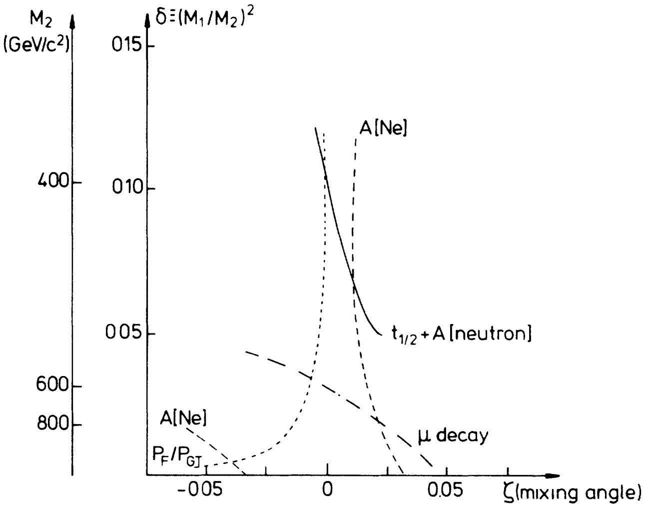

FIG. 1. Restrictions on the boson mixing angle ζ and the squared mass ratio $\delta \equiv (M_1/M_2)^2$ (for definition cf. text) provided by the muon-decay asymmetry (Refs. 6 and 7), the nuclear-β-decay asymmetry (Ref. 11), and relative Fermi and Gamow-Teller longitudinal polarizations (Ref. 8). We compare these constraints to that deduced from the combination of the neutron-decay asymmetry (Ref. 14), half-life (Ref. 22), and superallowed-pure-Fermi-decay probabilities (Ref. 18). The allowed region in Figs. 1-4 is that near $\zeta = \delta = 0$. In each case the curves correspond to 90% confidence.

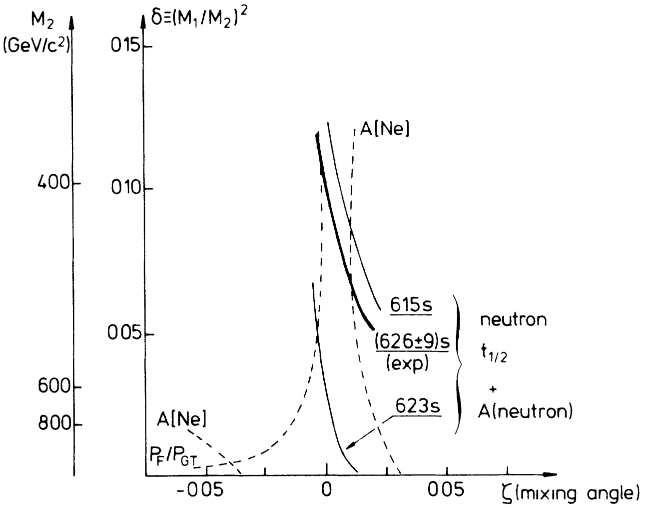

FIG. 2. Constraints deduced from β-decay data alone. The full lines show the constraints provided by neutron decay for the two extreme half-lives compatible with the pure $V-A$ theory extracted from Fig. 4 and the lowest half-life (626 − 9 sec) allowed by its experimental value (Ref. 22).

constraints on left-right-symmetric models which can be inferred from these experiments.[15] In this Rapid Communication, we report the outcome of this investigation.

The zero-momentum asymmetry quoted in Ref. 3 was written for positron decay but can be readily generalized for positron-electron transitions:

$$A=\pm 2\frac{g_A(g_A\pm g_V)-yg_A(yg_A\pm xg_V)+T_1}{g_V^2+3g_A^2+(x^2g_V^2+3y^2g_A^2)+T_2}\,. \tag{2}$$

Here the parameters x and y measure the deviation from the standard model and are expressed in terms of the right-handed parameters introduced above as

$$\begin{aligned} x&=\frac{\delta(1+\tan\zeta)-\tan\zeta(1-\tan\zeta)}{1-\tan\zeta+\delta\tan\zeta(1+\tan\zeta)}\cong\delta-\zeta\,,\\ y&=\frac{\delta(1-\tan\zeta)+\tan\zeta(1+\tan\zeta)}{1+\tan\zeta-\delta\tan\zeta(1-\tan\zeta)}\cong\delta+\zeta\,, \end{aligned} \tag{3}$$

while T_1 and T_2 are small corrections arising from recoil effects such as weak magnetism.[16] For a superallowed decay of small momentum transfer, as in neutron β decay, such corrections are less than 5×10^{-3} and have been neglected in our analysis. Finally g_A and g_V are the conventional axial-vector and vector semileptonic coupling constants. In the notation of Ref. 16 their ratio is positive: $g_A/g_V\approx1.26$.

The experimental value of the asymmetry provides constraints on the left-right-symmetric model parameters only if the coupling-constant ratio g_A/g_V is known. This ratio can be extracted from a parity-conserving observable such as the electron-neutrino directional correlation or the neutron ft value combined with that for superallowed pure Fermi transitions.

The electron-neutrino directional correlation coefficient a has been measured but only to a precision of 5.1%:[17]

$$a=-0.1017\pm0.0051\,. \tag{4}$$

The deduced value $g_A/g_V=1.259\pm0.017$ turns out to be less precise than that determined from the neutron lifetime and will not be considered further.

The extraction of the ratio g_A/g_V from the neutron-decay probability calls for the knowledge of the ft value for the superallowed pure Fermi (0^+-0^+) transitions as well as that for the neutron. As a result of the recent reevaluation of the $O(Z\alpha^2)$ radiative corrections to the 0^+-0^+ ft values,[18] the data base has become coherent and yields the Fermi ft value to a precision of 0.06%:

$$ft^{0^+\text{-}0^+}=3068.6\pm1.8\ \text{sec}\,. \tag{5}$$

In the case of the neutron, while the phase-space factor f is calculated quite precisely,[19]

$$f=1.7147\pm0.0002\,, \tag{6}$$

the same cannot be said of the neutron lifetime, for which a rather wide range of values have been reported.[20] Fortunately this situation is due to be cleared up. With the advent of novel experimental techniques[13] and with a number of lifetime measurements underway[21] results are expected eventually at about the 0.5% level of precision. In the present note, for illustrative purposes, we utilize the most recent value of which we are aware,[22]

$$t=903\pm13\ \text{sec}\,, \tag{7}$$

which yields

$$R=\frac{ft^{0^+\text{-}0^+}}{ft^n}=2.86\pm0.04\,, \tag{8}$$

and, neglecting right-handed currents, corresponds to the value

$$\frac{g_A}{g_V}=1.254\pm0.011\,. \tag{9}$$

The constraint associated with the lifetime ratio, Eq. (8), is imposed by the use of Eq. (10) of Ref. 3, which is identical for electron and positron decays:

$$R=\frac{g_V^2+3g_A^2+(x^2g_V^2+3y^2g_A^2)+T_3}{2(1+x^2)g_V^2+T_4}\,. \tag{10}$$

Again T_3 and T_4 are tiny corrections to neutron and 0^+-0^+ Fermi decay ft values arising from recoil effects that we have neglected as above in the case of recoil terms T_1 and T_2 (cf. also Refs. 19 and 23).

In Fig. 3, we display the rather wide (ζ,δ) parameter region still compatible with the best available information[14,23] on neutron decay. In Fig. 2 we compare the neutron-β-decay restrictions from Fig. 3 to those obtained by other means in order to illustrate the complementarity of these constraints. We observe that in the β-decay sector the constraints provided by the neutron decay are essential to delimit the mass region for the hypothetical heavy boson W_2. Moreover, even at their current level of precision, these bounds are comparable to the usefulness

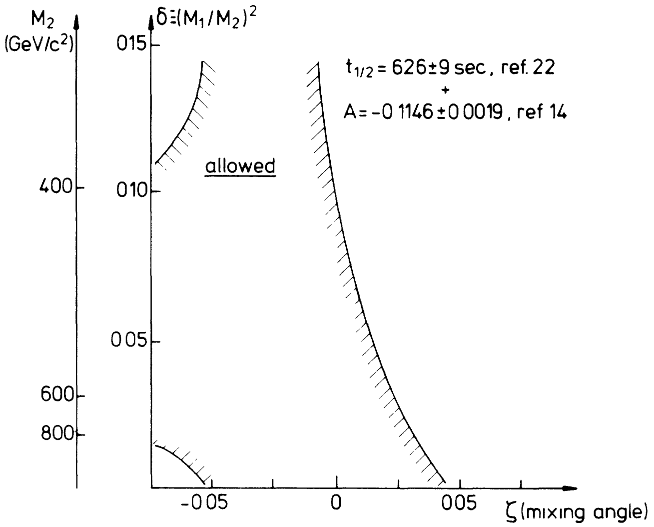

FIG. 3. Constraints deduced from neutron decay (Refs. 14 and 22) and superallowed pure Fermi transitions (Ref. 18) alone.

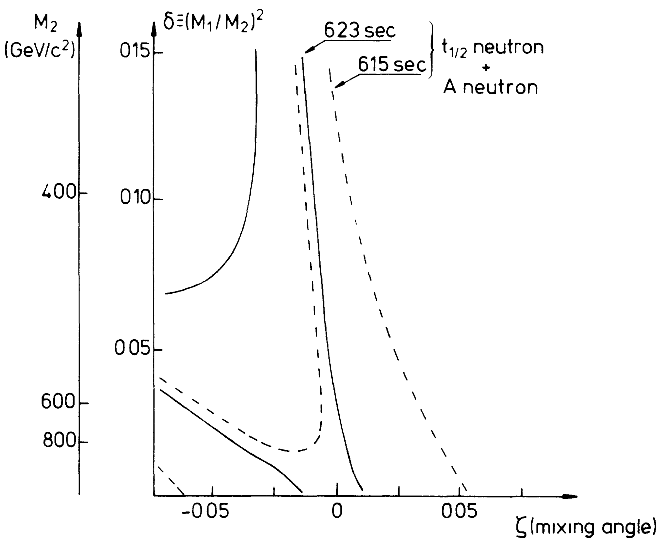

FIG. 4. The dependence of the constraints on the neutron half-life; the experimental values of the neutron decay asymmetry (Ref. 14) and superallowed-Fermi-decay probabilities (Ref. 18) are used. We show the constraints which would be provided by the extreme half-life values (615 and 623 sec; dashed and solid lines) still compatible with the pure $V-A$ theory.

of muon-decay experiments.

Finally, in order to illustrate the significance of the information one can expect from the ongoing neutron lifetime measurements, we show, in Fig. 4, the constraints obtained from two extreme half-life values still compatible with the absence of right-handed currents. In Fig. 2 we compare the constraints deduced from these two extremes with the other available β-decay information, which clearly illustrates the importance of the expected neutron-lifetime measurements.

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