port No. LBL-5334 (unpublished).

[11]If we assume that charm burning is negligible at $\sqrt{s} = 4.028$ GeV, then we expect that $\sim 40\%$ of the events at that energy involve charmed-meson production. Were there no charm-burning operative at $\sqrt{s} = 4.4$ GeV, a similar fraction of the events there would be charmed. But, data indicate a charm yield at 4.4 GeV of $\sim\frac{1}{3}$ that at 4.028 GeV, so that "charm burning" must account for $\sim 27\%$ of the events at 4.4 GeV. More than $\frac{1}{3}$ of the charm-burning processes should yield J/ψ.

[12]The concept of charm burning was first discussed by Okun' and Voloshin, Ref. 6.

Second-Class Currents

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We show that *effective* nuclear second-class axial-vector currents provide a consistent description of the available β-decay data and probe the fundamental structure of weak currents.

The recent correlation experiments[1] in nuclear β decay, if taken at their face value, would suggest the presence of an alarmingly large G-parity irregular component[2] (second-class currents, hereafter denoted by SCC) in weak interaction Hamiltonian. This appears to be at variance with the conclusion reached from the ensemble of data on ft asymmetries in mirror Gamow-Teller transitions.[3] To dramatize the seemingly conflicting nature of the two results, we state the present situation in terms of the naive impulse approximation: The correlation data imply a SCC form factor g_T as large as or even larger than the first-class weak magnetism form factor whereas careful analyses of mirror asymmetries, in particular in the mass-8 system,[4] would suggest $g_T \approx 0$ within large uncertainties in the nuclear-induced effects. In view of the enormous difficulties in accomodating second-class currents in modern gauge theories,[5] a vital question for a viable theory of anomalous currents to face is whether the contradictory observations can be reconciled in a natural and consistent way. The ensuing discussion is based on the assumption that the correlation data are not in error and therefore the effects are genuine.

In this Letter, we show that the model of *effective nuclear* second-class axial-vector currents proposed by us several years ago[6] which incorporates mesonic effects properly can indeed reconcile most, if not all, of the conflicting observations, and we suggest that nuclear many-body effects through which this occurs can play a unique and crucial role in providing information on the basic structure of the current. In particular it is shown that the class of models involving solely Fermion fields with derivative couplings is completely ruled out.

We start by briefly describing the ingredients that enter into the KDR model. In analogy with the description of the electromagnetic nuclear current[7] which has been found to be extremely successful,[8] we construct a nuclear SCC with an impulse-approximation term and a two-body meson-exchange current. As in Ref. 6, we shall confine ourselves to the simplest nontrivial account of possible off-shell effects by taking the second-class current coupling to off-shell nucleons in the form

$$i(g_T \sigma_{\mu\lambda} q_\lambda \gamma_5 + i g_T' P_\mu \gamma_5) \tag{1}$$

with q_μ and P_μ the difference and the sum, respectively, of the initial and final nucleon momenta. The meson-exchange currents are given by the "pair" term and the "$\omega\pi$" term of Ref. 6. The matrix element for $\omega \to \pi e \nu$ contributing to the latter can be written in the limit of low-pion momentum q in the form

$$iF_\omega S_\lambda + O(q). \tag{2}$$

Here S_λ is the polarization four-vector of the ω meson and F_ω a form factor, real if time-reversal invariance holds. Just as in the case of the electromagnetic current, we have used the notion that the exchanged pion is soft,[7] so that the expression (2) provides the relevant amplitude.

It was shown in Ref. 6 that all the observables can be described entirely by the two constants

$$\zeta \equiv g_T + g_T',$$
$$\lambda \equiv \frac{m_\pi^3 g_{\pi NN}^2}{24\pi m_N^2}\left(g_T' - \frac{g_{\omega NN} F_\omega}{g_{\pi NN} m_\omega^2}\right). \tag{3}$$

Equation (1) tells us that the constant ζ governs neutron β decay, reflecting directly the strength of the *basic* SCC. The quantity λ, however, is a complicated object that in general bears no direct relation to ζ. Now in terms of ζ and λ, the correlation measurements[1,9] effectively measure, *not ζ directly as the naive impulse picture implies*, but the A (nucleus)-dependent combination[10]

$$\kappa_A = \zeta + \lambda L_A, \tag{4}$$

and ft mirror asymmetries are given by

$$\delta_A^{\mathrm{SCC}} = -4\lambda J_A/g_A + \tfrac{4}{3}(\tfrac{1}{2}\lambda L_A - \zeta)W/g_A, \tag{5}$$

where W is the sum of the energy releases in β^+ and β^- decays and $g_A = 1.25$. In these expressions, L_A and J_A are ratios of two-body SCC to one-body axial-current matrix elements. Equation (5) is not applicable to the Wilkinson-Alburger (WA) plot of the $A = 8$ system [denoted by $\delta_8(W)$], except at $W = W_R$, the energy at the resonance point R, because of an *intrinsic* energy dependence of the broad final state.[6] Kubodera[11] has recently shown that the energy dependence of J and L is qualitatively different from that of the single-particle operator. His simplified expression, valid for $W \gtrsim 10$ MeV, is:

$$\delta_8^{\mathrm{SCC}}(W) = (-\tfrac{4}{3}\zeta - 4\lambda J_R/W_R)W/g_A + \tfrac{2}{3}\lambda L_R W^2/g_A W_R. \tag{6}$$

Note that Eq. (6) reduces to Eq. (5) at $W = W_R$, as it should.

The set of Eqs. (3)–(6) is the simplest nontrivial form with enough predictive power that one can write down incorporating minimal off-shell and mesonic effects. Without changing the structure, one can make these expressions more general than implied by the model by treating ζ and λ as *independent parameters* in analyzing the data: The meaning of ζ would remain unaltered. Here we take this point of view, returning to their explicit structure when considering specific models of the basis SCC.

In our analyses of ft asymmetries, odd-mass nuclei have been left out since nuclear effects due to the Coulomb force are difficult to estimate.[3] We have ignored also those nuclei for which correlations have been measured for only one of the mirror branches on the ground that in this case SCC effects cannot be unambigously extracted. An exception to this is the case of transitions between members of isomultiplets (e.g., $A = 19$) for which symmetry arguments assure that the first-class contributions are under control provided the strong form of conservation of vector current (CVC) holds.

In Table I, we have listed the calculated values of J_A and L_A for those nuclei whose wave functions are reliably known. All but mass 19 are taken from the KDR paper.[6] For mass 19, $J_{19} \equiv 0$ because it involves an isodoublet transition and L_{19} is calculated with an SU(3) wave function known to describe correctly the ground-state magnetic moment and the ft value. What is noteworthy here is that while J_A varies smoothly, L_A is strongly fluctuating, an important feature for understanding the nonsystematic behavior of the observed δ^{SCC}.

The WA data[4] fix the ratio λ/ζ rather accurately as shown in Fig. 1. Requiring consistency with the correlation data κ_{12} and κ_{19}[1] leads to (D in Fig. 1)

$$\zeta = (-3.3 \pm 0.9) \times 10^{-3}\ \mathrm{MeV}^{-1} = (-6.2 \pm 1.8)/2m_N, \tag{7}$$

$$\lambda = (5.4 \pm 2.0) \times 10^{-3}. \tag{8}$$

TABLE I. Comparison between KDR model and experiments (the errors quoted in the theory columns correspond only to the variation of λ and ζ within the area D of Fig. 1).

	Theory				Experiment	
A	L (MeV^{-1})	J	$2m_N\kappa$	δ^{SCC} (%)	$2m_N\kappa$	δ^{SCC} (%)
8	-0.252	3.52	-8.8 ± 2.6	1.8 ± 1.7(10[b])	-0.6 ± 1.0[c]	2.1 ± 3.8[e]
12	0.086	2.99	-5.3 ± 1.7	6.4 ± 2.0(12[b])	-4.4 ± 1.6[d]	-2 ± 3.1[e]
12*[a]	-0.807	5.31	-14.4 ± 4.7	-6.6 ± 3.5(9.0[b])	...	-10.4 ± 7.4[e]
18	-0.090	1.30	-7.1 ± 1.9	-1.3 ± 0.8(1.0[b])	...	-1.3 ± 1.3[e]
19	-0.167	0	-7.9 ± 2.3	...	-10.3 ± 4.1[d]	...

[a]Decay to the excited state of ^{12}C.
[b]Prediction by a divergenceless SCC.
[c]Ref. 9.
[d]Ref. 1.
[e]Ref. 3.

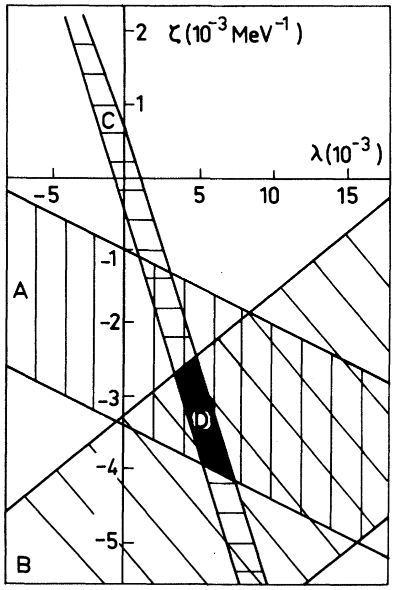

FIG. 1. Allowed values of ζ and λ for $\kappa_{12}(A)$, $\kappa_{19}(B)$, and the WA data, C. For the band C, "trivial" nuclear effects $\delta^{\mathrm{nucl}}=0.085\pm0.04$ for all W are subtracted from observed asymmetries to give δ^{SCC} (Ref. 3). The shaded area D corresponds to the results used in the text.

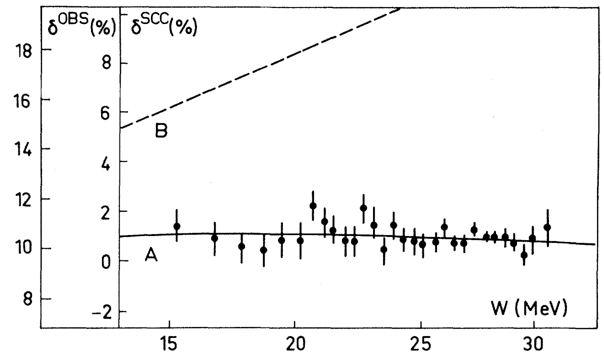

FIG. 2. Comparison of theories with experiments (Ref. 4) for the WA plot. The solid line A is the prediction of our theory and the dashed line B the result of a divergenceless current for $g_T=-7.4/2m_N$ corresponding to the average of κ_{12} and κ_{19}.

The correlation coefficients κ and the mirror asymmetries δ^{SCC} implied by these values are given and compared with the empirical data in Table I. Finally, we show in Fig. 2 the WA plot predicted by our model. We have thus succeeded in explaining the following features: (a) the magnitudes of κ_{12} and κ_{19}; (b) small $\delta_8^{\mathrm{SCC}}(W_R)$ and $\delta_{18}^{\mathrm{SCC}}$, consistent with zero; (c) large and negative $\delta_{12*}^{\mathrm{SCC}}$; (d) the slope of $\delta_8^{\mathrm{SCC}}(W)$ compatible with zero. The theoretical value of $\delta_{12}^{\mathrm{SCC}}$ seems a little bit too large, but this may not be significant in view of the large uncertainties in nuclear corrections[12] and we would not view this as a disagreement. The major problem probably lies with the $\beta\alpha$ correlation data[9] in $A=8$. If the data were naively interpreted in terms of κ, our model would be in serious trouble. However in view of the complex final states involved, we consider this an unsettled issue, both experimentally and theoretically.

Apart from the correlation data, there is no unequivocal evidence for a large SCC. Thus other independent measurements are urgently needed. An alternative explanation might be that the strong form of CVC is violated in the way suggested by Wolfenstein[10] and/or that second-class vector currents contribute by meson exchange. Here we shall suppose that our explanation of the diverse phenomena is not a mere accident and proceed to discuss how the nuclear many-body effects (through J and L) can discriminate among various classes of models suggested for the SCC. For this purpose, it is useful to classify the SCC by its divergence. The simplest divergenceless current that one can construct out of bilinear quark fields $\bar{q}q$ is

$$A_\mu^{\mathrm{II}}(x)=g_{\mathrm{II}}(\partial/\partial x_\lambda)\bar{q}(x)\sigma_{\mu\lambda}\gamma_5 q(x). \tag{9}$$

This form may be postulated as a basic (nonrenormalizable) current[13] or induced by strong interaction within the framework of gauge theories.[14] Since $\partial_\mu A_\mu^{\mathrm{II}}=0$, λ *should vanish* independently of its detailed structure.[6] Consequently the result becomes identical to the naive impulse approximation with $g_T'\doteq0$ in Eq. (1). To see how this fares, we have taken $g_T=\frac{1}{2}(\kappa_{12}^{\mathrm{exp}}+\kappa_{19}^{\mathrm{exp}})$ and calculated δ^{SCC} and $\delta_8^{\mathrm{SCC}}(W)$; the results are given, respectively, in parentheses in Table I and by a dashed line in Fig. 2. They are in violent disagreement with the data; thus such a current along with the strength compatible with the correlation data can be safely ruled out.

Now consider a SCC whose divergence is nonvanishing.[15] One such current is the phenomenological one constructed out of meson fields,[16,17]

$$\vec{A}_\mu^{\mathrm{II}}(x)=iF_\omega\omega_\mu(x)\vec{\pi}(x). \tag{10}$$

To our knowledge, this cannot arise naturally in currently accepted gauge theories.[5] If one applies the soft-pion theorem to the pion production amplitude with this current, then the set of Eqs. (4)-(6) is completely described by the commutator of A_μ^{II} with the axial charge, which in the σ model is just proportional to the ω field.[17]

The "pair" current is suppressed, so we get just the "$\omega\pi$" exchange current of Ref. 6, the only parameter of the theory being F_ω. The net effect is to drop g_T' from Eq. (3), giving rise to a unique relation for λ in terms of ζ. To see whether this model makes sense, it is necessary to evaluate g_T from the current (10). We are unable to do this fully satisfactorily, but we can get an order-of-magnitude idea by saturating the matrix element of Eq. (10) by nucleon intermediate states alone.[6,17] The results depend rather sensitively on the cutoff mass M used in the πNN and ωNN form factors. For a common mass $M = 0.9$ GeV (1 GeV), we obtain a ratio $\lambda/\xi = 4.90$ MeV (-4.02 MeV) which agrees in sign and in order of magnitude with the empirical value -1.6 ± 0.5 MeV. In view of our ignorance on the contributions from other intermediate states, this may not be too significant; however, the rough agreement suggests that this simple one-parameter model is not utterly absurd.

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Quadrupole Moment of the Second 2^+ State of ^{184,186}W†

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We have performed a thick-target particle-γ coincidence experiment to measure $q(2^{+\prime})$, the quadrupole moment of the second 2^+ state, of ^{184,186}W. We have also determined $q(2^{+\prime})$ of ^{186}W by an independent method involving particle spectroscopy. Neither the rotation-vibration nor the asymmetric rotor model can explain the results. Kumar-Baranger calculations agree with the trend.

Much systematic information has now been obtained on the spectroscopic quadrupole moment of first excited nuclear states via the reorientation effect. Little is known of the higher-lying states, since such experiments require high-precision measurements which become more difficult with increasing excitation energy. It is of interest to extend these measurements to higher-lying collective levels which are not members of the ground-state band and whose nature is less well understood. ^{186}W and ^{184}W each have a second 2^+ state, at 737 and 904 keV, respectively,