THE STILL INTERESTING WEAK HYPERON DECAYS*, **

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Weak hyperon decays present us with a couple of interesting problems. After discussing hyperon nonleptonic decays to set a reliable reference basis, we review the status of the long-standing puzzle of weak radiative hyperon decays and the question of validity of Hara's theorem. The conflict between expectations based on Hara's theorem and experiment as well as the violation of that theorem in the quark and vector meson dominance models are briefly discussed. The importance of upcoming experiments as tests of Hara's theorem is stressed. Significant role of hyperon nonleptonic decays in search for direct CP violation is also pointed out.

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1. Introduction

Weak hyperon decays provide us with an opportunity to study unsolved interesting questions both in the CP conserving and in the CP violating sector. In both types of problems a good understanding of ordinary nonleptonic hyperon decays is a necessary prerequisite. Consequently, we start from a presentation of a model of nonleptonic hyperon decays that describes the data with a minimal number of free parameters and thus may serve as a fairly reliable input for more penetrating questions (Section 2). We then move on to the puzzle of weak radiative hyperon decays and the question of the validity of Hara's theorem relevant for these decays (Section 3). The theorem itself and its violation in the quark and vector-meson dominance models are confronted with existing experimental results. The importance

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of upcoming experiments that should provide crucial phenomenological information is stressed. In Section 4 we discuss the question of direct CP-violation and the opportunities offered here by weak nonleptonic hyperon decays. Theoretical estimates of CP-violating asymmetries to be measured are also briefly reviewed there.

2. Nonleptonic hyperon decays

In nonleptonic hyperon decays the task of a theorist is to decribe the parity violating (S-wave) A amplitudes and the parity conserving (P-wave) B amplitudes with the help of a minimal number of parameters. Reliable theoretical predictions of the overall scale of each of the amplitude sets are not yet possible. The best that can be achieved is the *simultaneous* explanation of the SU(3) structure of both amplitude sets. This SU(3) structure is determined by the ratio of the two SU(3) invariant couplings f, d which parametrize the matrix element of the parity conserving part of the weak Hamiltonian

$$\langle B_f \mid H^{p.cons.}_{\mathbf{weak}} \mid B_i \rangle = f \,\mathrm{Tr}\,(\lambda_6[B_i, B_f^\dagger]) + d\,\mathrm{Tr}\,(\lambda_6\{B_i, B_f^\dagger\}) \qquad (1)$$

(here λ_6 represents the spurion describing SU(3) properties of the weak Hamiltonian).

In the quark model the W-exchange amplitude of Fig. 1.1 leads to the prediction $f/d = -1$ in total disagreement with the data that require f/d equal to -2.5 (-1.8) for parity violating (conserving) amplitudes. Comparison of data with SU(3)-symmetry fits is given in Table I.

Attempts to explain the departure of f/d from its standard valence quark model value of -1 involve, among others, the inclusion of "penguin" diagrams visualised in Fig. 1.2 (the quark in the virtual loop is understood to undergo strong interaction with the remaining two quarks). Such diagrams yield $d = 0$, $f \neq 0$ and thus may be blamed for the apparent difference between the experiment and the naive quark model. Detailed short-distance calculations show that the size of the effect is five times too small [1], however. On the other hand, if one uses the value of the strong coupling constant needed to explain the Δ - N splitting one obtains $f/d \approx -1.5$ (in the parity conserving sector) [2]. Similar value ($f/d \approx -1.6$) is obtained in approaches in which quark loop of Fig. 1.2 is generated via hadron-level loops (meson-cloud effects whose scale is set by the Δ - N splitting again) [3].

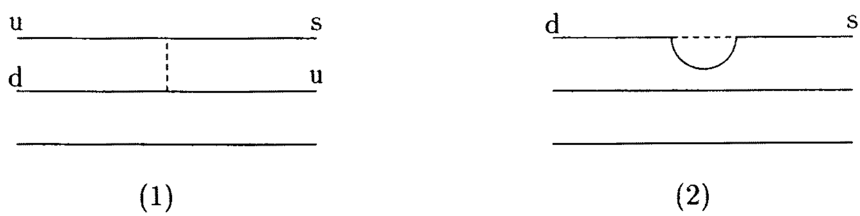

Fig. 1. Quark diagrams for the baryon-to-baryon matrix elements of the parity conserving part of the weak Hamiltonian.

TABLE I

SU(3) description of weak nonleptonic hyperon decays

	A		B	
process	exper.	SU(3) fit f/d= -2.5	exper.	SU(3) fit f/d= -1.8
$\Lambda \to p\pi^-$	3.25	3.47	22.1	17.5
$n\pi^0$	-2.37	-2.45	-15.8	-12.4
$\Sigma^+ \to n\pi^+$	0.13	0.00	42.2	42.0
$p\pi^-$	-3.27	-3.18	26.6	29.0
$\Sigma^- \to n\pi^-$	4.27	4.50	-1.44	0.8
$\Xi^0 \to \Lambda\pi^0$	3.43	3.17	-12.3	-12.0
$\Lambda\pi^-$	-4.51	-4.49	16.6	17.0

Thus, independently of whether the dominant contribution is of short- or long-range, there are good indications that the deviation of f/d from -1 is due to diagrams of "penguin" topology.

The value of -2.5 obtained for f/d from an analysis of parity violating amplitudes relies on the use of current algebra. This technique is SU(3) symmetric and hence subject to SU(3)-breaking corrections. Since current algebra corresponds to the SU(3) symmetric limit of the pole model (Fig. 2), it should be possible to include such SU(3)-breaking corrections at the baryon level. In Ref. [4] it was shown that in that case the relation between the values of f/d for the parity conserving and the parity violating amplitudes is

$$\left(\frac{f}{d}+1\right)_{p.\text{viol.}} = \frac{1+\frac{\delta s}{\Delta\omega}}{1-\frac{\delta s}{\Delta\omega}}\left(\frac{f}{d}+1\right)_{p.\text{cons.}}, \tag{2}$$

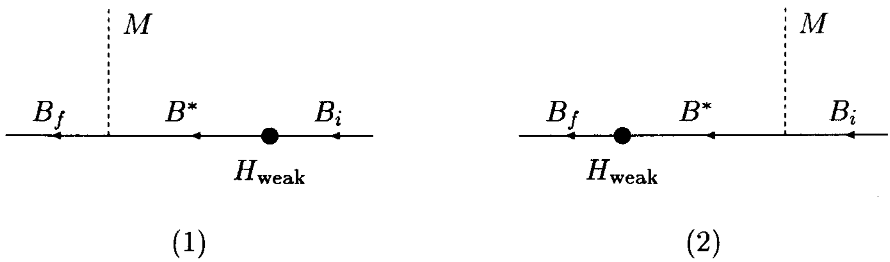

Fig. 2. Baryon-pole diagrams for weak decays.

where $\delta s \approx 190$ MeV is the strange-nonstrange quark mass difference and $\Delta\omega \approx 570$ MeV is the excitation energy of $1/2^-$ baryons (For more details see Ref. [5]). Using experimental values of f/d's, Eq. (2) reads then $-1.5 \approx 2*(-0.8)$. Thus, we have a relatively good phenomenological understanding of SU(3) symmetry and its breaking in nonleptonic hyperon decays. This is important for more challenging questions encountered in weak radiative hyperon decays and in CP-violating effects in nonleptonic hyperon decays.

3. Weak radiative hyperon decays

Long history of unsuccessful theoretical approaches has led theorists to view the problem of WRHD's as "a long-standing discrepancy" [6], an "unsolved puzzle" [7] or "the long-standing $\Sigma^+ \to p\gamma$ puzzle" [8]. Recently, their actual status has been extensively reviewed by Lach and the author [9].

WRHD's are rare strangeness-changing decays of hyperons into other ground-state baryons plus a photon. There are five experimentally observed WRD of ground-state octet baryons: $\Sigma^+ \to p\gamma$, $\Lambda \to n\gamma$, $\Xi^0 \to \Sigma^0\gamma$, $\Xi^0 \to \Lambda\gamma$, $\Xi^- \to \Sigma^-\gamma$. Theoretical problems manifest themselves most clearly in the description of the $\Sigma^+ \to p\gamma$ decay. This particular decay should satisfy a fairly fundamental theorem proved in 1964 by Hara [10]. It is therefore very interesting to note that

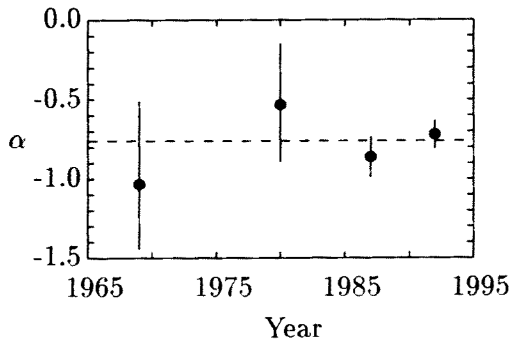

Fig. 3. History of measurement of $\Sigma^+ \to p\gamma$ asymmetry parameter.

- explicit quark model calculation violates Hara's theorem
- quark and vector-meson dominance models lead to the same SU(3) symmetry structure of the amplitudes and agree with experiment better than those approaches in which Hara's theorem is satisfied.

Hara's theorem, proved at hadron level, reads:

Parity-violating amplitude A of the $\Sigma^+ \to p\gamma$ decay vanishes in exact $SU(3)$-flavour symmetry.

For a nonzero parity-conserving amplitude B one then expects decay asymmetry

$$\alpha = \frac{2Re(A^*B)}{|A|^2 + |B|^2} \tag{3}$$

to be small since SU(3) is usually broken weakly.

Current experimental evidence, summarized in Fig.3, shows beyond any doubt that asymmetry in question is *large* (and *negative*). The most recent number, coming from the E761 experiment performed at Fermilab [11], is based on nearly 35 thousand events.

A first reaction to the above discrepancy between experiment and theory is to assign the disagreement to a stronger than usual SU(3)-symmetry breaking. (This is one of the reasons calling for good understanding of SU(3) symmetry and its breaking in closely related nonleptonic hyperon decays). In reality the situation is much more involved and delicate: in 1983 Kamal and Riazuddin showed [12] that Hara's theorem is *violated in the quark model also in the SU(3) limit.* In 1989 the author [13] considered a vector-meson-dominance approach to weak radiative hyperon decays (that violates Hara's theorem explicitly) and proposed to understand the quark-model result via VDM. A full and complete understanding of why the quark and vector-meson dominance models lead to the same answer seem to be still missing, however.

3.1. Hara's theorem

Since the quark (and the vector dominance) model violates Hara's theorem even in the SU(3) limit, our attention should be focussed on other assumptions needed in its proof. However, the only other assumptions seem to be those of gauge- and CP-invariance. Gauge invariance requires that in the most general hadron-photon parity violating coupling

$$\overline{\Psi}_p\gamma_5(\gamma_\mu F_1(q^2) + q_\mu F_2(q^2) + F_3(q^2)\sigma_{\mu\nu}q^\nu)\Psi_{\Sigma^+}A^\mu \tag{4}$$

one has $F_1(0) = 0$ and, consequently, for real, transverse, final photons ($q^2 = q_\mu A^\mu = 0$) only the F_3 term contributes.

CP-invariance (which relates $p \leftrightarrow \overline{p}$, $\Sigma^+ \leftrightarrow \overline{\Sigma}^-$) requires that full coupling of the p, Σ^+ initial baryons and the Σ^+, p final baryons to real photons is

$$F_3(q^2)(\overline{\Psi}_p\gamma_5\sigma_{\mu\nu}\Psi_{\Sigma^+} - \overline{\Psi}_{\Sigma^+}\gamma_5\sigma_{\mu\nu}\Psi_p)q^\nu A^\mu \tag{5}$$

which is *antisymmetric* under $\Sigma^+ \leftrightarrow p$ interchange. Since the weak Hamiltonian is *symmetric* under $s \leftrightarrow d$ ($\Sigma^+ \leftrightarrow p$) interchange (SU(3) limit) we must have $F_3 = 0$ and, consequently, the parity-violating $\Sigma^+ \to p\gamma$ amplitude vanishes.

One might therefore expect that the quark-model violation of Hara's theorem results from breaking either gauge- or CP-invariance in quark-level calculations. Quark-model calculations are, however, explicitly gauge- and CP-invariant, whether one uses the potential model [12] or the bag model [14].

In the past an additional problem was caused by the sign of the $\Sigma^+ \to p\gamma$ asymmetry. Namely, assuming that the $\Sigma^+ \to p\gamma$ decay is dominated by the single-quark diagram of Fig. 4a, one can show [9, 15] that the asymmetry in question is

$$\alpha(\Sigma^+ \to p\gamma) = \frac{m_s^2 - m_d^2}{m_s^2 + m_d^2} \tag{6}$$

which is positive (+0.4 or +1.0 for constituent or current quark masses respectively) and thus in disagreement with experiment. Recent precise measurements of the $\Xi^- \to \Sigma^-\gamma$ branching ratio [16] (which proceeds through diagram (4a) only) prove, however, that there is no way of reproducing the $\Sigma^+ \to p\gamma$ branching ratio by assuming the dominance of diagram (4a): the predicted branching ratio is then too small by a factor of one hundred.

3.2. Quark diagrams

Out of all topologically possible quark diagrams shown in Fig. 4, contribution from diagrams (c) vanishes in the SU(3) limit and is negligible in explicit calculations with broken SU(3) [9, 17]. Diagrams (d) are suppressed by the presence of two W propagators. Thus, since (a) is negligible, it is contribution from diagrams $(b1)$ and $(b2)$ *only* that may be significant. Violation of Hara's theorem results from this very set of quark diagrams both in the quark model [12] and in the vector-meson dominance approach [13].

1. Quark diagrams and the standard pole model

At the hadron level diagrams $(b1)$ and $(b2)$ should correspond (dominantly) to the contribution from intermediate $\frac{1}{2}^-$ excited baryons. Using the quark model one can calculate the $\frac{1}{2}^+ \to \frac{1}{2}^-$ weak transition elements and the $\frac{1}{2}^- \to \frac{1}{2}^+ + \gamma$ electromagnetic couplings. Their relative size is governed by various group-theoretical spin-flavour factors. When one identifies the results of these quark model calculations with *those hadron-level* expressions that are *allowed by gauge invariance*, one finds that contributions from diagrams $(b1)$ and $(b2)$ must enter with a relative minus sign, thus ensuring cancellation (in the SU(3) limit) of the corresponding contributions to the $\Sigma^+ \to p\gamma$ decay[17]. In explicit models SU(3) is broken in energy denominators of the intermediate excited $\frac{1}{2}^-$ baryons. Since $m_{N^*} - m_{\Sigma^+} = \Delta\omega - \delta s$, $m_{\Sigma^*} - m_p = \Delta\omega + \delta s$ (see Eq. (2)), diagrams $(b1)$ and $(b2)$ - having different energy denominators - do not cancel exactly [17]. The corresponding formulae (up to an uninteresting normalization factor) are given in column 2 of Table II, where $x \equiv \frac{\delta s}{\Delta\omega} \approx \frac{1}{3}$. *By construction* the obtained $\Sigma^+ \to p\gamma$ parity violating amplitude vanishes in the SU(3) limit $(x \to 0)$.

2. Quark diagrams and quark model calculations

There is, however, no reason to identify quark model calculations of the $\frac{1}{2}^+ \to \frac{1}{2}^-$ weak transition elements and the $\frac{1}{2}^- \to \frac{1}{2}^+ + \gamma$ electromagnetic couplings with hadron-level expressions first and only later combine them to form full amplitudes for WRHD's. One can perform all calculations at the strict quark level and only eventually evaluate the resulting expression in between the initial and final hadronic states. These direct quark-model calculations (potential model [12], bag model [14]) yield amplitudes proportional to the sum of spin-flavour factors corresponding to diagrams $(b1)$ and $(b2)$. In a consistent quark-level calculation the relative sign of spin-flavour factors of diagrams $(b1)$ and $(b2)$ is obviously *fixed* and it turns out to be *positive*. With a relative positive sign the contributions of diagrams $(b1)$

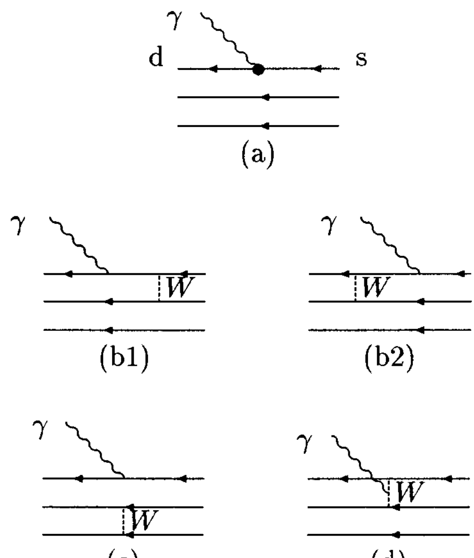

Fig. 4. Quark diagrams for weak radiative hyperon decays.

and $(b2)$ add rather than cancel resulting in the violation of Hara's theorem (see column 3, Table II).

TABLE II

Parity violating amplitudes with SU(3) breaking:
$(b1)-(b2)$ — Hara's theorem satisfied,
$(b1)+(b2)$ — Hara's theorem violated.

process	$(b1)$-$(b2)$	$(b1)$+$(b2)$
$\Sigma^+ \to p\gamma$	$-\frac{2x}{3\sqrt{2}}$	$-\frac{2}{3\sqrt{2}}$
$\Lambda \to n\gamma$	$+\frac{2x-1}{3\sqrt{3}}$	$+\frac{2-x}{3\sqrt{3}}$
$\Xi^0 \to \Lambda\gamma$	$+\frac{1-x}{3\sqrt{3}}$	$-\frac{1-x}{3\sqrt{3}}$
$\Xi^0 \to \Sigma^0\gamma$	$+\frac{1+x}{3}$	$+\frac{1+x}{3}$

3. Quark diagrams and vector-meson dominance

The problem seems to be therefore:

- if one applies gauge invariance at hadron level (original proof of Hara's theorem, or pole model with $\frac{1}{2}^-$ intermediate baryons) — Hara's theorem is satisfied
- if one applies gauge invariance at quark level — Hara's theorem is violated.

In order to understand this one needs a way to *translate* the gauge-invariance condition from the quark to the hadron level (instead of using an *ad hoc* identification prescription). A possible way to do it was proposed by Kroll, Lee and Zumino [18]. According to the KLZ scheme, translation of quark-level interactions with a photon to the hadron-level language is provided by the vector dominance model (VDM).

Standard VDM prescription is formulated at the *hadron level* and consists in:

1. calculating vector meson (V^μ) couplings to hadrons (H_1, H_2) through $< H_2|J^V_\mu|H_1 > V^\mu$ where J^V_μ are quark currents
2. replacing vector mesons by photons through $V^\mu \to \frac{e}{g_V} A^\mu$ (where $g_\rho = 5.0$).

The latter step may be obtained at a theoretical level by introducing a gauge-invariance-violating coupling $e\frac{m_V^2}{g_V} V \cdot A$ that induces photon mass. In the KLZ scheme one adds additional terms to cancel this photon mass so that gauge invariance is restored. Then, after redefining photon and vector-meson fields as well as electric charge, the VDM prescription turns out to be just a *good approximation to the quark-level* prescription in which photons couple to quarks directly and in an explicitly gauge-invariant way: $< H_2|J^V_\mu|H_1 > A^\mu$ (for details see [9, 18, 19]).

The KLZ scheme sheds some light on the violation of Hara's theorem in the quark model [13]. Namely, explicit calculations of diagrams ($b1$) and ($b2$) with photon replaced by vector meson show that the coupling $\Sigma^+ \to p$ + (*U-spin singlet vector meson*) does not vanish.

Since no gauge-invariance condition is imposed in vector-meson case the obtained coupling may be identified with the $F_1(q^2)\overline{\Psi}_p\gamma_5\gamma_\mu\Psi_{\Sigma^+}V^\mu$ term with a nonvanishing $F_1(0)$ [20]. Thus, the Kroll–Lee–Zumino scheme suggests that the quark-model result should correspond to the VDM-generated effective coupling $F_1(0)\overline{\Psi}_p\gamma_5\gamma_\mu\Psi_{\Sigma^+}A^\mu$ that does not vanish at $q^2 = 0$. This coupling was absent in the original derivation of Hara's theorem in which therefore, according to KLZ scheme, *contribution from pointlike quarks is simply not taken into account.* The correspondence of the VDM result with strict quark model calculations of Kamal and Riazuddin is not complete, however: the original KR result arises from the propagation of a "free" quark in between the action of the weak Hamiltonian and the emission of the photon. This leads to a pole at zero photon momentum, a pole that is absent in the VDM approach.

3.3. Comparison with experiment

When parity-violating amplitudes of Table II are supplemented with standard description of parity-conserving amplitudes one obtains different signatures for hadron- and quark-level predictions (see Table III).

TABLE III

Signs of asymmetries
$(b1) - (b2)$ — Hara's theorem satisfied,
$(b1) + (b2)$ — Hara's theorem violated.

process	$(b1) - (b2)$	$(b1) + (b2)$
$\Sigma^+ \to p\gamma$	–	–
$\Lambda \to n\gamma$	–	+
$\Xi^0 \to \Lambda\gamma$	–	+
$\Xi^0 \to \Sigma^0\gamma$	–	–

Namely, if Hara's theorem is satisfied (as in standard hadron-level approaches) *all* four asymmetries are of the *same* sign. On the other hand, if the quark-model route (or vector meson dominance) is strictly followed, Hara's theorem is violated and the asymmetries of the $\Lambda \to n\gamma$ and the $\Xi^0 \to \Lambda\gamma$ decays are *opposite* to those of $\Sigma^+ \to p\gamma$ and $\Xi^0 \to \Sigma^0\gamma$. Phenomenologically, the $\Xi^0 \to \Lambda\gamma$ decay is a much cleaner case than $\Lambda \to n\gamma$ (see Ref. [9]). It is therefore extremely important that the asymmetry of the $\Xi^0 \to \Lambda\gamma$ be precisely measured. Current data (Table IV) on the $\Xi^0 \to \Lambda\gamma$ asymmetry reject Hara's theorem at an almost 3σ level. When other asymmetries and branching ratios are taken into account the disagreement with Hara's theorem is even more significant (Table IV).

We are therefore eagerly awaiting the results of the hyperon decay program in the E832 KTeV experiment at Fermilab, where the expected number of $\Xi^0 \to \Lambda\gamma$ events is 900, a factor of 10 greater than the number of events observed thus far. Measurements of the $\Xi^0 \to \Sigma^0\gamma$ asymmetry, planned in the same experiment, are also important: for this decay *all* models predict negative (and often large) asymmetries while the only experiment performed so far does not support a large negative asymmetry. Measurements of the branching ratio and asymmetry of the $\Lambda \to n\gamma$ (where theoretical predictions are less reliable due to phenomenological uncertainties) will be performed as a part of the E781 experiment. This experiment will also attempt to measure better the parameters of the $\Xi^- \to \Sigma^-\gamma$ decay (and to confirm the results obtained previously for $\Sigma^+ \to p\gamma$). Results of both experiments are expected within two years.

TABLE IV

Asymmetries and branching ratios — comparison of two selected conflicting models and experiment

process	Ref. [17] Hara th. satisfied	exp.	Ref. [9] Hara th. violated
	Asymmetries		
$\Sigma^+ \to p\gamma$	$-0.80^{+0.32}_{-0.19}$	-0.76 ± 0.08	-0.95
$\Lambda \to n\gamma$	-0.49		$+0.80$
$\Xi^0 \to \Lambda\gamma$	-0.78	$+0.43 \pm 0.44$	$+0.80$
$\Xi^0 \to \Sigma^0\gamma$	-0.96	$+0.20 \pm 0.32$	-0.45
	Branching ratios (in units of 10^{-3})		
$\Sigma^+ \to p\gamma$	$0.92^{+0.26}_{-0.14}$	1.23 ± 0.06	$1.3 - 1.4$
$\Lambda \to n\gamma$	0.62	1.63 ± 0.14	$1.4 - 1.7$
$\Xi^0 \to \Lambda\gamma$	3.0	1.06 ± 0.16	$0.9 - 1.0$
$\Xi^0 \to \Sigma^0\gamma$	7.2	3.56 ± 0.43	$4.0 - 4.1$

I believe that in a few years' time predictions of the quark and vector-dominance models will be better confirmed experimentally. The problem will then be to understand these predictions at a deeper theoretical level. The *basic assumptions* of the quark model seem to lead to a *conflict* with the standard way of imposing gauge-invariance condition at hadron level. Consequently, it seems that one must either modify something in the quark model or admit that the standard way of imposing the gauge-invariance condition at hadron level is somehow deficient. So far there is no accepted solution of this puzzle posed by WRHD's.

4. CP violation in hyperon decays

CP violation has been observed in the $\Delta S = 2$ strangeness changing processes only (*i.e.* in the mass matrix of the kaon system). So far the search for CP nonconservation in relevant decay amplitudes has been inconclusive. Detection of such a "direct" CP violation constitutes now a goal of several experiments (see Ref. [21]). "Direct" CP violation should in principle contribute to many processes such as $K \to 2\pi$, $K \to \pi^+\pi^-\gamma$, $K_L^0 \to \pi^0 e^+ e^-$, as well as B and hyperon decays. However, in many of these decays direct CP violation contributes alongside the somewhat more standard CP violation in mass matrix. Hyperon decays are valuable in this respect because they provide a direct measure of the $\Delta S = 1$ CP nonconservation: any CP violation observed in these decays must of necessity be $\Delta S = 1$.

In the standard Kobayashi–Maskawa model [22] the $\Delta S = 1$ CP-violating effects arise from the penguin diagram (Fig. 1.2) [23]. On the other hand some non-standard theories (*e.g.* superweak model [24]) have no such $\Delta S = 1$ effects. Thus, hyperon decays may provide a place where differentiating between various underlying theories becomes possible. For this reason experiments have been approved [25] to study CP violation in $\Lambda \to p\pi^-$ (and in $\Xi \to \Lambda\pi$) decays. In these decays experimentally the most accessible CP-violating parameter is asymmetry A:

$$A = \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}}, \tag{7}$$

where α is the asymmetry of the hyperon decay

$$\alpha = \frac{2Re(S^*P)}{|S|^2 + |P|^2} \tag{8}$$

with S, P being the parity violating and parity conserving amplitudes respectively. The $\overline{\alpha}$ parameter measures asymmetry in related antihyperon decay. Under CP transformation we have $\alpha \leftrightarrow -\overline{\alpha}$ and, consequently, in the CP-conserving world the A asymmetry vanishes. The current experimental number for A is -0.03 ± 0.06.

Observation of CP violation in hyperon decays requires not only a CP-violating phase in weak decay amplitudes but also a phase from final-state strong interactions. Neglecting the $\Delta I = 3/2$ decay amplitudes one can write approximate expression for $A(\Lambda \to p\pi^-)$, which — to leading order in all the small parameters — is [26, 27]

$$A(\Lambda^0_-) = -\tan(\delta_P - \delta_S)\sin(\phi_P - \phi_S), \tag{9}$$

where $\delta_{P(S)}$ is the final-state strong rescattering phase, and $\phi_{P(S)}$ - the CP-violating weak phase in the $P(S)$ (isospin $I = 1/2$) wave. Values of δ are taken from experiment and/or calculated in a model. Since the whole asymmetry A is proportional to the difference of (small) strong phases it is obvious that good understanding of strong amplitudes and scattering phases is needed [27]. Furthermore, a good handle on penguin diagrams (which determine weak phases) is also needed. Phenomenological determination of the size of penguin contribution attempted in Sect. 2 is therefore important.

The penguin diagram contribution involves complex KM factors:

$$V^*_{ud}V_{us}\,L(u) + V^*_{cd}V_{cs}\,L(c) + V^*_{td}V_{ts}\,L(t), \tag{10}$$

and vanishes only for degenerate quarks u, c, t when all loop contributions $L(q)$ become equal and one can use the KM matrix property $\Sigma V^*_{qd}V_{qs} = 0$. For non-degenerate quarks Eq. 10 generates nonvanishing contributions at both short- and long-range distances. Short-distance estimates of penguin-induced CP-violating effects in hyperon decays have been performed in Refs. [26, 27, 28]. Using various models such as vacuum saturation, MIT bag model etc the short-distance contribution to the CP-violating parameter $A(\Lambda^0_-)$ is estimated in Refs. [26, 27, 28] to be at the level of 10^{-5} up to a factor of two to three. In Sect. 2 it was argued that in hyperon decays the diagrams of penguin topology may be dominated by long-distance effects. Thus, it is important to see what purely long-distance dynamics would predict for the value of A. In such a calculation the contribution from virtual hadronic loops involving the top quark is negligible on account of the very large mass of the top hadrons appearing in energy denominators. Thus, the long-distance-induced CP violation arises essentially from the u, c sector. In Ref. [29] it was estimated that the relevant long-distance contribution to the asymmetry in question may be of the order of $A(\Lambda^0_-)_{\text{long-distance}} \approx 10^{-5}$, *i.e.*

of similar size as the short-distance contribution. Because of the approximate equality of short- and long-distance contributions the experimental observation of asymmetry of this order should be interpreted with great care.

The upcoming E871 experiment is expected to reach sensitivity of 10^{-4} for the sum of CP-violating asymmetries $A(\Lambda^0_-)$ and $A(\Xi^-_-)$ [25] (this sum — as theoretical calculations indicate — is presumably dominated by $A(\Lambda^0_-)$). Although this sensitivity seems a little too small to permit detection of direct CP violation at the standard model level, it is obvious that we are approaching a stage when detecting direct CP violation becomes possible. Weak hyperon decays may provide us with some important new information here.

5. Conclusions

Important progress in precision experiments made over the years permits performing now previously not feasible measurements of such rare processes as weak radiative hyperon decays or of CP violating asymmetries in hyperon nonleptonic decays. Through these processes various problems of fairly fundamental nature may be tested. These problems address such important issues as the question of a proper gauge-invariant description, in the presence of parity violating interactions, of a baryon treated as a composite system of quarks or the search for direct CP violation. Thus, studies of weak hyperon decays promise to constitute a very interesting field in the years to come.

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