Dispersive contribution to CP violation in hyperon decays

P. Żenczykowski
Department of Theoretical Physics, The H. Niewodniczański Institute of Nuclear Physics, Radzikowskiego 152, Kraków, Poland

(Received 17 April 1996)

Within the standard model, CP-violating asymmetries $A(\Lambda^0_-)$ and $A(\Xi^-_-)$ have been estimated in short-distance calculations to occur at the level of 10^{-5}. We show here that in this model the dispersive contribution tends to give asymmetries of similar size. [S0556-2821(97)04203-3]

PACS number(s): 11.30.Er, 13.30.Eg

A lot of interest is now directed towards understanding the origin of CP violation in particle physics [1]. Among various processes considered as promising areas of experimental study, the nonleptonic hyperon decays offer the possibility to observe CP violation in $\Delta S=1$ transitions. The upcoming E871 experiment is expected to reach sensitivity of 10^{-4} for the sum of CP-violating asymmetries $A(\Lambda^0_-)$ and $A(\Xi^-_-)$ [2]. Estimates of these asymmetries within standard model yield values at a few times 10^{-5} level [3,4]. It has been stressed [3] that good understanding of the dominant CP-conserving part of nonleptonic hyperon decays as well as knowledge of strong interaction effects (and, in particular, of scattering phases) are indispensable if we are to draw meaningful conclusions from any observed signal of CP violation.

Recently an economic and successful model of the CP-conserving part of hyperon nonleptonic decays has been proposed [5]. The success of the model stems from allowing a substantial (relative to W exchange) total penguin contribution in baryon-to-baryon weak transitions. In agreement with general requirements of chiral and weakly broken SU(3) symmetries the contributions from diagrams with weak Hamiltonian acting in the meson leg were assumed nondominant. Without introducing *any* additional parameters the model of [5] generates then a relation between the values of the f/d ratios for S and P waves, which agrees with experiment very well. While the deviation of f/d from -1 is, in the model, due to penguin diagrams, the origin of the difference in the values of the f/d ratios for the two waves arises from SU(3) breaking in the intermediate states. In short, the approach fixes the size of (the real part of) the total penguin contributions in the S and P waves.

Short-distance estimates of the CP-conserving part of the penguin contribution in hyperon decays yields values that fall short of the data by a factor of at least 5 [6]. A similar factor of 5 is needed in kaon decays as well. Arguments have been presented that such factors presumably originate from long-range hadron-level effects [7–9]. If hadron-level effects are indeed that important, then for a reliable estimate of the CP-violating penguin contribution one has to consider both hadron-level (dispersive) and short-distance effects. However, the estimates of CP violation in hyperon decays carried out so far are based on short-distance calculations only [3,10,11].

In general, calculations of the scale of dispersive effects may easily differ between various approaches by a factor of 5 or more. In order to proceed we assume in the following that the total penguin contribution to nonleptonic hyperon decays is dominated by hadron-loop effects. If these effects are smaller, the numbers calculated below should be scaled down appropriately.

In Ref. [5] we have obtained a description of the Λ^0_- and Ξ^-_- decays given in Table I, where contributions due to penguin diagrams are explicitly shown. [The relevant reduced SU(6) matrix elements b (W exchange) and c (penguin) are (in units of 10^{-7}): (1) for the S waves: $b_S=-5$, $c_S=12$ with $(f/d)_S=-1+2c_S/(3b_S)=-2.6$ and (2) for the P waves: $b_P=-132$, $c_P=158$ with $(f/d)_P=-1+2c_P/(3b_P)=-1.8$.] A description of the P-wave amplitudes for $F/D=0.57$ is given in Table I as well.

The hadron-level penguin contribution arises from that part of hadronic loops which, when viewed at the quark level, generates quark loops with $q=u,\ c$, and t (Fig. 1). Its real part, of interest to us, may be estimated through dispersion relations. Contribution from hadronic states involving t quarks may be safely neglected: the relevant thresholds are very remote. On the other hand, dispersive effects which correspond to u and c quark loops have to be considered. Although we will neglect direct contribution from the top

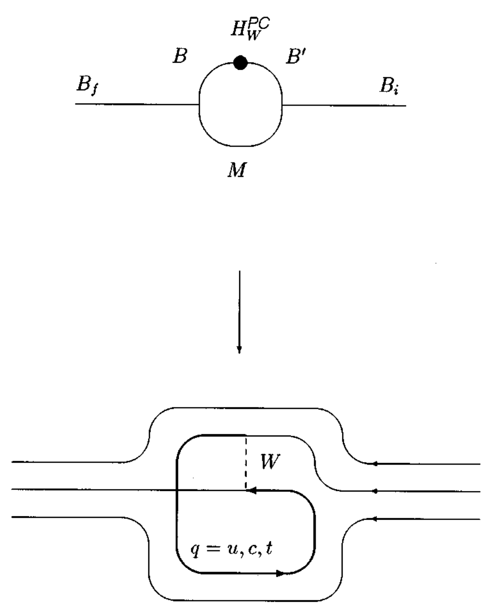

FIG. 1. Example of quark-loop generation from a hadron-level loop diagram for the baryon-to-baryon matrix element of the parity conserving part of the weak Hamiltonian.

TABLE I. Full amplitudes and penguin contributions in CP-conserving amplitudes of nonleptonic hyperon decays (from Ref. [5]).

	Wave	SU(3) expression	Penguin contribution	Total	Experiment
Λ^0_-	S	$-\frac{1}{2\sqrt{6}}b_S+\frac{1}{2\sqrt{6}}c_S$	2.45	3.47	3.23
	P (F/D)				
	2/3	$\frac{1}{6\sqrt{6}}b_P+\frac{1}{2\sqrt{6}}c_P$	32.3	23.3	22.1
	0.57		29.2	17.6	
Ξ	S	$\frac{1}{\sqrt{6}}b_S-\frac{1}{2\sqrt{6}}c_S$	−2.45	−4.49	−4.50
	P (F/D)				
	2/3	$-\frac{1}{3\sqrt{6}}b_P-\frac{1}{6\sqrt{6}}c_P$	−10.8	7.2	16.6
	0.57		−7.7	15.5	

states, the existence of the t quark is felt in the u, c sector as a deviation from equality of $V^*_{ud}V_{us}$ and $-V^*_{cd}V_{cs}$:

$$V^*_{cd}V_{cs}=-V^*_{ud}V_{us}-V^*_{td}V_{ts}. \tag{1}$$

Thus, the sum of contributions from intermediate hadron states corresponding to quark loops is

$$\begin{aligned}&V^*_{ud}V_{us}L_H(u)+V^*_{cd}V_{cs}L_H(c)+V^*_{td}V_{ts}L_H(t)\\&\quad\approx V^*_{ud}V_{us}[L_H(u)-L_H(c)]-V^*_{td}V_{ts}L_H(c),\end{aligned} \tag{2}$$

where dependence on Kobayashi-Mashawa (KM) factors has been explicitly factored out of the hadron-level-induced loop contribution $L_H(q)$ of quark q. The second term on the right-hand side (RHS) of Eq. (2) induces CP violation. The size of the CP-violating term is governed by

$$\mathrm{Im}\tau\equiv\mathrm{Im}\frac{-V^*_{td}V_{ts}}{V^*_{ud}V_{us}}=A^2\lambda^4\eta\lesssim10^{-3} \tag{3}$$

(using $\lambda=0.22$, $A=0.9\pm0.1$, and $\eta\lesssim0.4\pm0.2$). A large mass of the c quark produces an additional suppression factor s_c, so that, in fact, the scale of CP-violating amplitudes relative to the CP-conserving one is set by

$$\mathrm{Im}\tau s_c\equiv\mathrm{Im}\tau L_H(c)/[L_H(u)-L_H(c)]. \tag{4}$$

To estimate the ratio of dispersive factors let us note that the long-range penguin contribution originates from weak transitions that occur within hadrons from intermediate meson +baryon virtual states. Loop factors $L_H(q)$ are proportional to the probability of finding such a virtual state in a physical baryon. For degenerate light u, d, s quarks this probability may be estimated in the dispersive approach as proportional to [12]

$$\int_{\mathrm{thr}}^{\infty}\frac{-\mathrm{Im}\Pi(s')}{(s-s')}{}^2ds', \tag{5}$$

where $\sqrt{s}$ is total baryon energy and $\sqrt{s'}$ is the energy of the virtual meson+baryon state. In the framework of the unitarized quark model of Törnqvist [13] the numerator in the integrand of Eq. (5) is proportional to

$$k'^3\exp[-(k'/k_{\mathrm{cutoff}})^2], \tag{6}$$

where the first factor comes from the phase space and the p-wave character of strong virtual decays, and the second factor arises from hadronic form factors and provides the cutoff. In realistically sized hadrons $k_{\mathrm{cutoff}}\approx0.7$ GeV [13]. The dominant contribution comes then from intermediate meson (baryon) momenta k' in the range $k'^2\approx0.6$–1.2 GeV^2.

Assuming SU(4) symmetric couplings, the dominant size difference between $L_H(u)$ and $L_H(u)$comes from different values of the denominator in Eq. (5). Thus, the ratio $L_H(c)/L_H(u)$ may be roughly estimated as

$$L_H(c)/L_H(u)\approx[(E'_{M_u}+E'_{B_u}-\sqrt{s})/(E'_{M_c}+E'_{B_c}-\sqrt{s})]^2, \tag{7}$$

where $E'_{M_q}=\sqrt{m^2_{M_q}+k'^2}$, $E'_{B_q}=\sqrt{m^2_{B_q}+k'^2}$ are energies of the intermediate meson and baryon containing loop quark q.

One then obtains $L_H(c)/L_H(u)\approx0.1$–0.2. In conclusion, dispersive calculations are expected to give s_c of the order of 10–20 %. A calculation of CP asymmetries is now straightforward. Normalizing the penguin contribution to the full amplitude according to Table I, one obtains the following weak phases:

$$\begin{aligned}\phi_S(\Lambda^0_-)&=+0.7s_c\mathrm{Im}\tau,\\ \phi_P(\Lambda^0_-)&\approx+1.35s_c\mathrm{Im}\tau,\\ \phi_S(\Xi^-_-)&=+0.54s_c\mathrm{Im}\tau,\\ \phi_P(\Xi^-_-)&\approx-0.55s_c\mathrm{Im}\tau.\end{aligned} \tag{8}$$

The CP-violating asymmetries are then calculated from the formula [3]

$$A=-\tan(\delta_P-\delta_S)\sin(\phi_P-\phi_S) \tag{9}$$

which is valid if one neglects the experimentally small $\Delta I=3/2$ transitions (in the model employed these transitions vanish identically). In Eq. (9) $\delta_{P,S}$ are phase shifts due to final-state strong interactions in appropriate isospin states

($I=1/2$ for Λ^0_- and $I=1$ for Ξ^-_-). With $\mathrm{Im}\tau\approx 10^{-3}$ and using $I=1/2$ phase shifts $\delta_P(\Lambda^0_-)=-1.1°$, $\delta_S(\Lambda^0_-)=+6.0°$ from Ref. [14] one gets

$$A(\Lambda^0_-)=0.081 s_c \mathrm{Im}\tau\approx(0.8-1.6)\times 10^{-5}. \tag{10}$$

For the Ξ^-_- decays the relevant strong rescattering phases were calculated both in the past [15], with the result $\delta_P(\Xi^-_-)=-2.7°$ and $\delta_S(\Xi^-_-)=-18.7°$ corresponding to the asymmetry

$$A(\Xi^-_-)=0.31 s_c \mathrm{Im}\tau\approx(3-6)\times 10^{-5} \tag{11}$$

as well as more recently [16], in which case smaller values were obtained: $\delta_P(\Xi^-_-)=-1.7°$ and $\delta_S(\Xi^-_-)=0.2°$ leading to

$$A(\Xi^-_-)=-0.036 s_c \mathrm{Im}\tau\approx-(0.35-0.7)\times 10^{-5}. \tag{12}$$

Comparing the above results for $A(\Lambda^0_-)$, $A(\Xi^-_-)$ with the estimates of Refs. [3] and [4] we conclude that dispersive contributions to asymmetries in question may be of the same order as their short-distance counterparts. Thus, experimental observation of asymmetry of this order should be interpreted with great care.

This research was supported in part by the Polish Committee for Scientific Research Grant No. 2 P03B 231 08.

[1] For a recent review see B. Winstein and L. Wolfenstein, Rev. Mod. Phys. **65**, 1113 (1993).

[2] J. Russ, Nucl. Phys. **A585**, 39c (1995); J. Antos *et al.*, Fermilab Report No. P-871 (unpublished); G. Gidal, P. Ho, K. B. Luk, and E. C. Dukes, Fermilab Report No. E871 (unpublished).

[3] J. Donoghue, X.-G. He, and S. Pakvasa, Phys. Rev. D **34**, 833 (1986); X.-G. He, H. Steger, and G. Valencia, Phys. Lett. B **272**, 411 (1991).

[4] X.-G. He and G. Valencia, Phys. Rev. D **52**, 5257 (1995).

[5] P. Żenczykowski, Phys. Rev. D **50**, 3285 (1994); Acta Phys. Pol. B **26**, 851 (1995).

[6] J. F. Donoghue, E. Golowich, W. A. Ponce, and B. R. Holstein, Phys. Rev. D **21**, 186 (1980); J. F. Donoghue, E. Golowich, and B. Holstein, Phys. Rep. **131**, 319 (1986).

[7] H. Y. Cheng, Int. J. Mod. Phys. A **4**, 495 (1989).

[8] N. Isgur, K. Maltman, J. Weinstein, and T. Barnes, Phys. Rev. Lett. **64**, 161 (1990); P. Żenczykowski, Phys. Rev. D **54**, 907 (1996).

[9] P. Żenczykowski, Phys. Rev. D **45**, 3153 (1992). Contributions from intermediate charmed meson and baryon states estimated in this paper lack an additional minus sign that arises from the KM matrix and ensures Glashow-Iliopoulos-Maiani cancellation in the dispersive sector. This omission does not change the conclusions of the paper since contributions from charmed hadron loops are small.

[10] F. J. Gilman and M. B. Wise, Phys. Lett. **83B**, 83 (1979).

[11] In the kaon sector, hadron-level contributions to CP-violating effects were discussed by L. Wolfenstein, Nucl. Phys. **B160**, 501 (1979); C. T. Hill, Phys. Lett. **97B**, 275 (1980); J. F. Donoghue and B. R. Holstein, Phys. Rev. D **29**, 2088 (1984).

[12] S. Ono and N. A. Törnqvist, Z. Phys. C **23**, 59 (1984).

[13] N. A. Törnqvist, Acta Phys. Pol. B **16**, 503 (1985); P. Żenczykowski, Ann. Phys. (N.Y.) **169**, 453 (1986).

[14] L. Roper *et al.*, Phys. Rev. **138**, 190 (1965).

[15] R. Nath and B. R. Kumar, Nuovo Cimento **36**, 669 (1965); B. Martin, Phys. Rev. **138**, 1136 (1965).

[16] M. Lu, M. Savage, and M. Wise, Phys. Lett. B **337**, 133 (1994); A. Datta and S. Pakvasa, *ibid.* **344**, 430 (1995).