Mirror matter admixtures and isospin breaking in the $|\Delta I| = 1/2$ rule in $\Omega^-$ two body non-leptonic decays

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Abstract

We discuss a description of $\Omega^-$ two body non-leptonic decays based on possible, albeit tiny, admixtures of mirror matter in ordinary hadrons. The $|\Delta I| = 1/2$ rule enhancement is obtained as a result of isospin symmetry and, more importantly, the rather large observed deviations from this rule result from small isospin breaking. This analysis lends support to the possibility that the enhancement phenomenon observed in low energy weak interactions may be systematically described by mirror matter admixtures in ordinary hadrons.

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The enormous gap that exists from strong and electromagnetic interactions to weak interactions offers a rather unique opportunity to either put very stringent lower bounds on or to indirectly detect effects of the existence of new matter, through its mixing with ordinary one. One attractive form of this new matter may be mirror matter, initially discussed by Lee and Yang [1] in their seminal paper on parity violation and later systematically studied by many authors [2]. Of particular interest is the possibility that small admixtures of mirror hadrons in the ordinary ones may help describe the enhancement phenomenon and its accompanying $|\Delta I| = 1/2$ rule observed in non-leptonic and weak radiative decays of the latter. After so many years of its discovery [3] this phenomenon still awaits a thorough description. If mirror matter admixtures are to help in this respect, one should demand that it does so in a systematic way and in terms of only a few mixing angles that show a universality property. Otherwise it would be of little help.

We have studied this possibility in a series of publications [4]. To implement such mixings it is necessary to introduce an ansatz, because no one is yet able to perform the necessary QCD first principle calculations that enable one to obtain such mixings starting at the quark level. In terms of that ansatz one obtains results that comply with the above demands. A satisfactory description for non-leptonic and weak radiative decays of hyperons and non-leptonic decays of pseudoscalar mesons is obtained. The mixing angles come out very small, albeit tiny, at around $10^{-6} - 10^{-7}$. It is no surprise then that a very high lower bound on the mass of mirror hadrons can be set, at around $10^6$GeV [5]. The origin of these numbers is the gap mentioned in the beginning. Recently, under a separate cover [6], we extended this approach to the two-body non-leptonic decays of $\Omega^-$. The $|\Delta I| = 1/2$ rule is obtained as a result of isospin symmetry and the comparison with experiment is encouraging. However, a precise description of the data was not yet obtained, because the isospin symmetry limit was assumed.

It is the purpose of this paper to study the effects of such breaking on the mirror admixtures in $\Omega^-$ non-leptonic decays. This is delicate because experimentally the $|\Delta I| = 1/2$ rule in the modes $\Omega^- \to \Xi^-\pi^0$ and $\Omega^- \to \Xi^0\pi^-$ is obeyed only to around 35% in the quotient
of the corresponding branching ratios and in this approach this deviation can be attributed only to isospin breaking. This should be contrasted with $W$-mediated non-leptonic decays. Violations of this rule there are attributed to a large $|\Delta I| = 3/2$ piece in the effective hamiltonian. Here we must explain a 35% deviation with small isospin breaking. We shall see this to be the case.

Amplitudes of $\Omega^-$ decays with isospin breaking. As a start, let us briefly review the results of Ref. [6]. Following the ansatz discussed earlier [4], the mirror admixtures in $\Omega^-$ are

$$
\Omega^-_{ph} = \Omega^- - \sqrt{3}\sigma\Xi^-_{s} + \sqrt{3}\delta\Xi^-_{p} + \cdots
$$

Our phase conventions are those of Ref. [7].

Eq. (1) is to be used together with the expressions with the mixings in the $s = 1/2$ baryons and pseudoscalar mesons relevant here, namely,

$$
\Xi^-_{ph} = \Xi^- - \sigma\Sigma^-_{s} + \delta'\Sigma^-_{p} + \cdots
$$

$$
\Xi^0_{ph} = \Xi^0 - \sigma\frac{1}{\sqrt{2}}\Sigma^0_{s} + \sqrt{3}\frac{3}{2}\Lambda_{s} + \delta'\frac{1}{\sqrt{2}}\Sigma^0_{p} + \sqrt{3}\frac{3}{2}\Lambda_{p} + \cdots
$$

$$
\Lambda_{ph} = \Lambda_{s} + \sigma\sqrt{3}\frac{3}{2}(\Xi^0_{s} - n_{s}) + \delta\sqrt{3}\frac{3}{2}\Xi^0_{p} + \delta'\sqrt{3}\frac{3}{2}n_{p} + \cdots
$$

$$
\pi^0_{ph} = \pi^0 - \sigma\frac{1}{\sqrt{2}}(K^0_{p} + \bar{K}^0_{p}) + \delta\frac{1}{\sqrt{2}}(K^0_{s} - \bar{K}^0_{s}) + \cdots
$$

$$
\pi^-_{ph} = \pi^- + \sigma\bar{K}^{-}_{p} + \delta K^{-}_{p} + \cdots
$$

$$
K^-_{ph} = K^- - \sigma\pi^{-}_{p} + \delta'\pi^{-}_{s} + \cdots
$$

The transition operator is the strong-interaction flavor and parity-conserving hamiltonian responsible for the two-body strong decays of the other $s = 3/2$ resonances in the decuplet.
where $\Omega_s$ belongs to. The parity-conserving and parity-violating amplitudes $B$ and $C$ in the decay amplitude $\bar{u}(p')(B + \gamma^5C)q^\mu u_\mu(p)$ of $\Omega^-$ (in a standard notation) are given by

$$B(\Omega^- \to \Xi^-\pi^0) = -\sigma(\sqrt{3}g_{\pi\Xi^-\Xi^+} + \frac{1}{\sqrt{2}}g_{\eta\Xi^-\Xi^+}),$$

(8)

$$C(\Omega^- \to \Xi^-\pi^0) = \delta'(\sqrt{3}g_{\pi\Xi^-\Xi^+} - \frac{1}{\sqrt{2}}g_{\eta\Xi^-\Xi^+}),$$

(9)

$$B(\Omega^- \to \Xi^0\pi^-) = \sigma(\sqrt{3}g_{\pi\Xi^-\Xi^+} + g_{K^-\Xi^0\Omega^-}),$$

(10)

$$C(\Omega^- \to \Xi^0\pi^-) = \delta'(\sqrt{3}g_{\pi\Xi^-\Xi^+} + \delta g_{K^-\Xi^0\Omega^-}),$$

(11)

$$B(\Omega^- \to \Lambda K^-) = \sigma(\sqrt{3}g_{K^-\Xi^0\Xi^+} + \sqrt{3}g_{K^-\Xi^0\Omega^-}),$$

(12)

$$C(\Omega^- \to \Lambda K^-) = \delta'(\sqrt{3}g_{K^-\Xi^0\Xi^+} + \delta\sqrt{3}g_{K^-\Xi^0\Omega^-}).$$

(13)

The $g_{MB'B'}$ in these amplitudes are the Yukawa coupling constants observed in the strong decays $B \to B'M$. The constants $g_{M_pB_s'B_p'}$, $g_{M_sB_s'B_p'}$ and $g_{M_pB_p'B_s}$ are new, because they involve mirror matter. The subindices $s$ and $p$ stand for positive and negative parity, respectively. Our assumptions about the $SU(3)$ properties of mirror $s = 3/2$ resonances require that the absolute values of their Yukawa couplings be the same as the corresponding ones of ordinary $s = 3/2$ resonances. However, their phases may differ.

We have no assumed in Eqs. (8) – (13) isospin symmetry. For comparison purposes let us reproduce in Tables I and II the predictions obtained when one assumes this limit, when the $|\Delta I| = 1/2$ rule is valid. One can see in these tables that $\Gamma(\Omega^- \to \Xi^-\pi^0)$ and $\Gamma(\Omega^- \to \Xi^0\pi^-)$ differ by 16% and 12%, respectively, from their measured values. These two deviations give practically all of the $\chi^2$ of 25.16. Their ratio or rather its inverse is 2.07 and is smaller about 35% than the measured one of 2.74. In this mirror admixture approach these deviations must be explained by isospin breaking. One must recall that in this approach the $|\Delta I| = 1/2$ rule should more properly be named a $\Delta I = 0$ rule.
Effects of isospin breaking in the predictions for Ω⁻ decays. Since we do not assume isospin symmetry the constants $g_{η^0 ϖ^- Ξ^o^+}$ and $g_{η^- ϖ^o Ξ^o^-}$ and $g_{K^0 ϖ^- Ω^-}$ and $g_{K^- ϖ^o Ω^-}$ are allowed to vary separately, because they are no longer constrained to obey the $SU(2)$ symmetry relations $g_{η^- ϖ^o Ξ^o^-} = -\sqrt{2} g_{η^0 ϖ^- Ξ^o^+}$ and $g_{K^- ϖ^o Ω^-} = g_{K^0 ϖ^- Ω^-}$. The results are also displayed in Tables I and II. The main changes appear in $Γ(Ω⁻ → Ξ^− π^0)$ and $Γ(Ω⁻ → Ξ^0 π^-)$ and their corresponding parity-conserving amplitudes $B(Ω⁻ → Ξ^− π^0)$ and $B(Ω⁻ → Ξ^0 π^-)$. Percentage-wise these changes are $-15.4\%$, $+11.4\%$, $-8.0\%$, and $+5.6\%$, respectively. All percent changes we shall quote are with respect to the symmetry limit values. Changes in other observables and amplitudes are not perceptible at the two and even at the three digit level. With isospin breaking the description of the data is quite satisfactory.

To appreciate this breaking we must look first at the values of the parameters. Our $\chi^2$ consists of 10 restrictions, 3 weak decay rates, 3 asymmetries, 1 strong decay rate [8] and the values of the 3 angles from earlier work [4]. The latter are $σ = (4.9 \pm 2.0) \times 10^{-6}$, $δ = (2.2 \pm 0.9) \times 10^{-7}$, and $δ' = (2.6 \pm 0.9) \times 10^{-7}$. In the $SU(2)$ limit, the 6 parameters take the values $g_{η^0 ϖ^- Ξ^o^+} = 4.326\text{GeV}^{-1}$ ($= g_{η^0 ϖ^- Ξ^o^+}$), $g_{η^- ϖ^o Ξ^o^-} = -6.118\text{GeV}^{-1}$ ($= g_{η^- ϖ^o Ξ^o^-}$), $g_{K^0 ϖ^- Ω^-} = -10.35\text{GeV}^{-1}$ ($= -g_{K^0 ϖ^- Ω^-}$), $g_{K^- ϖ^o Ω^-} = -10.35\text{GeV}^{-1}$ ($= -g_{K^0 ϖ^- Ω^-}$), $g_{K^0 ϖ^- Ω^-} = g_{K^0 ϖ^- Ω^-}$, $g_{K^- ϖ^o Ω^-} = -7.773\text{GeV}^{-1}$ ($= -g_{K^- ϖ^o Ω^-}$), $σ = 5.10 \times 10^{-6}$, $δ = 2.63 \times 10^{-7}$, and $δ' = 2.15 \times 10^{-7}$. The second and fourth constants are fixed by $SU(2)$ and we have displayed in parentheses the phases used for the coupling constants involving mirror hadrons.

When isospin is broken the 8 parameters used take the values $g_{η^0 ϖ^- Ξ^o^+} = 4.322\text{GeV}^{-1}$, $g_{η^- ϖ^o Ξ^o^-} = -6.120\text{GeV}^{-1}$, $g_{K^0 ϖ^- Ω^-} = -10.36\text{GeV}^{-1}$, $g_{K^- ϖ^o Ω^-} = -10.34\text{GeV}^{-1}$, $g_{K^0 ϖ^- Ω^-} = -7.766\text{GeV}^{-1}$, $σ = 5.10 \times 10^{-6}$, $δ = 2.62 \times 10^{-7}$, and $δ' = 2.15 \times 10^{-7}$, with the same phases as above for the mirror couplings. These coupling constants are of the order of magnitude expected [9]. One can see that the angles remain unchanged from their symmetry limit to their symmetry breaking predictions. The first four couplings in these two lists change only in the third or even in the fourth digit. In percent, the changes in the ratios $(-\sqrt{2})g_{η^0 ϖ^- Ξ^o^+} / g_{η^- ϖ^o Ξ^o^-}$ and $g_{K^- ϖ^o Ω^-} / g_{K^0 ϖ^- Ω^-}$ are $-0.13\%$, and $-0.19\%$, respectively. This is indeed a small isospin breaking.
Relevant remarks. It is interesting to see how such a small breaking leads to a deviation of around 35% in the quotient of the branching ratios of $\Omega^- \rightarrow \Xi^- \pi^0$ and $\Omega^- \rightarrow \Xi^0 \pi^-$. We must concentrate on the $B$ amplitudes of these two decays, the $C$ amplitudes are kinematically suppressed and this explains the small values of the asymmetry coefficients. These amplitudes are particularly sensitive to isospin $SU(2)$ symmetry and to its breaking. An order of magnitude estimate shows this.

Looking at Eqs. (8) – (13) one sees that since the mixing angle $\sigma$ is of the order of $10^{-5} - 10^{-6}$ and the Yukawa couplings are of the order of 10 GeV$^{-1}$, the amplitudes are expected to be of the order of $10^{-7} - 10^{-8}$ MeV$^{-1}$. In contrast, they are of the order of $10^{-9}$MeV$^{-1}$. From Table II, $B(\Omega^- \rightarrow \Xi^- \pi^0) = -0.8889 \times 10^{-9}$MeV$^{-1}$ and $B(\Omega^- \rightarrow \Xi^0 \pi^-) = 1.257 \times 10^{-9}$MeV$^{-1}$ in the symmetry limit. So, experimentally our estimate must be reduced by over one order of magnitude. This is what $SU(2)$ symmetry achieves, but then the $B$ amplitudes become very sensitive to its breaking. Accordingly, a small breaking of around 0.20% in the couplings lead to the new values $B(\Omega^- \rightarrow \Xi^- \pi^0) = -0.8175 \times 10^{-9}$MeV$^{-1}$ and $B(\Omega^- \rightarrow \Xi^0 \pi^-) = 1.327 \times 10^{-9}$MeV$^{-1}$. The corresponding percent changes are $-8.0\%$ and $+5.6\%$. The ratios of these two amplitudes deviates around 15% from the $-1/\sqrt{2}$ value predicted by the $|\Delta I| = 1/2$ rule. Since the $B$’s dominate the branching ratios, the quotient $\Gamma(\Omega^- \rightarrow \Xi^0 \pi^-)/\Gamma(\Omega^- \rightarrow \Xi^- \pi^0)$ deviates around 35% from its 2.1 value of the $|\Delta I| = 1/2$ rule. A $-8.0\%$ or a $+5.6\%$ change in the $B$’s is large, and not because $SU(2)$ breaking is large but because the $B$’s are small.

$SU(2)$ symmetry becomes so relevant because of the demands we discussed above. It is necessary that the values of the mixing angles used here be the same as in earlier work and that the Yukawa couplings be of the right order of magnitude. The role of the strong decay rate $\Gamma_4$ in Table I is essential. Without this restriction those couplings would become wild, and the required suppression would be provided by a reduction of their magnitudes and not by the interplay of the $SU(2)$ Clebsch-Gordan coefficients.

In Ref. [5] we referred to the approach used here as manifest mirror symmetry, because it is assumed that the strong and electromagnetic interactions are shared with the same
intensity between mirror and ordinary matter [10]. These are the most favorable conditions under which mirror admixtures may give observable effects in our by large predominantly ordinary matter world.

Discussion and conclusion. The above analysis together with the previous ones shows that mirror-matter admixtures provide a systematic description of the enhancement phenomenon observed in non-leptonic meson, hyperon, and $\Omega^-$ decays (NLMD, NLHD, and NLOD) and in weak radiative decays of hyperons (WRD). At this point the question is what room is left for those contributions by the description of this phenomenon within the standard framework. We shall now address this question.

Theoretical investigations of the enhancement phenomenon have a long story (see Refs. [11–21] and references therein) and progress has been slow. It is a common understanding that its explanation is rooted in the dynamics of the strong interactions that dress the weak transition vertex. At present there is not yet a first principle QCD derivation of this effect. One must therefore resort to ways to address calculations, which lead to effective weak hamiltonians involving quasi-particle degrees of freedom. Necessarily, many parameters as low energy coupling constants or effective masses are introduced, limiting the predictive power. In the last decade an a half perturbative contributions have been shown to produce rather small enhancement. However, they do provide essential hints of how non-perturbative contributions should be incorporated in the low energy domain of QCD. Currently, a consensus has been reached that the major effect in understanding the $\Delta I = 1/2$ rule and its deviations is due to non-perturbative long distance contributions. However, comparison between different effective approaches is difficult. There are ambiguities from author to author and uncertainties in calculations may be largely amplified. In some cases (NLMD and NLHD) an effort is made to estimate a theoretical error, in others (WRD and NLOD) the predictions are less quantitative or simply qualitative.

Important attention has been paid to studying systematically the success of specific approaches in different groups of decays, in order to assess their overall success. The best numerical results in reproducing experimental measurements are obtained in NLMD and
NLHD. In Ref. [13] NLMD are analyzed and after adjusting a free parameter corresponding to unknown Fierz terms in factorization, the theoretical predictions carry a 20-30% uncertainty and the central values differ from experiment by 25-30%. Also in this reference [13] the results of [14] for NLHD are reviewed. Out of the 14 measured amplitudes 13 are reproduced between 1-20%, only one is missed by about 80%. The corresponding decay rates are all reproduced ranging from 1% to 30% [14]. The results of Ref. [15] for NLHD reproduce 4 of the $P$-waves amplitudes (only 4 are independent when exact isospin is assumed) very well between 1-5%; however, only 3 $S$-wave amplitudes are reproduced between 10-30% and one is missed badly (its sign is predicted opposite).

The approach of [13,14] has not been applied to WRD. In Ref. [16] WRD are studied, but its results are not quantitative. Experimental data is used to extract some parameters, which are then compared with their determination elsewhere. An order of magnitude agreement is observed. The approach of [15] has been extended to WRD [17]; however, only indicative results are expected. The large negative asymmetry of $\Sigma^+ \rightarrow p\gamma$ is reproduced, but the corresponding branching ratio is missed by an order of magnitude. Predictions within the standard framework for this group of decays are not yet quantitatively satisfactory.

The approaches of [13,14] and [15] have both been applied to NLOD [14,18]; although the authors make it clear that their results are mainly of qualitative nature and are not anticipated to reproduce precisely experimental numbers. Looking at the predictions of [14] one can see that the three decay rates are predicted within 30-50%. In [18] numerical results are better, at 5-10%; however, the authors emphasized that these results are not to be trusted yet. There are other predictions in the literature [19,20], whose approach is along the lines of [18]. Ref. [19] does not really make predictions, it is similar in spirit to [16], certain parameters are fitted and their order of magnitude is satisfactorily compared to independent determinations elsewhere. In contrast, Ref. [20] points out that the $\Delta I = 3/2$ amplitudes in NLOD turn out so large as to cast doubt on either experimental values or on the reliability of approximations of calculations of the analogous amplitudes in NLHD. A different effective approach is envisaged in Ref. [21]. Their predictions for decay rates,
however, turn out to be a factor of 2 off experiment.

To summarize our brief review of the work within the standard framework, let us say that (i) no first principle QCD calculations are yet available, (ii) there are many effective formulations which are difficult to compare with one another, however, (iii) predictions so far are encouraging and (iv) a systematic understanding of long range effects to produce enhancement is $\Delta S = 1$ non-leptonic hadronic decays is gradually emerging. We can now address our question: is there room for contributions of physics outside the standard framework in these decays? Currently the answer is affirmative. Guiding ourselves by the estimated theoretical errors and the accuracy of the predictions of Refs. [11–13,15,18] one may estimate that the enhancement produced in the standard framework leaves room for other contributions that ranges between 30-50%.

In view of our results above and of previous work and of this last discussion, one may conclude that in attacking the problem of the enhancement observed in $\Delta S = 1$ non-leptonic and radiative decays one should keep in mind that non-standard physics may contribute to this enhancement. The extent of this contribution will depend on the room left for it by standard framework contributions. Whether these latter will produce 50%, 70%, or even a full 100% of the observed enhancement will be determined beyond doubt by first principle calculations of QCD long range effects. This final answer is, however, not yet within our reach and may stay so for quite some time [11]. It is therefore very important in the meanwhile to remain open-minded and not to overlook potentially important contributions from outside the standard framework.

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TABLE I. Experimental decay rates and asymmetry coefficients and their predicted values. The upper entries assume isospin symmetry, the lower ones allow for breaking of the latter. The indices 1, 2, and 3 refer to the modes \( \Omega^- \rightarrow \Xi^0 \pi^0 \), \( \Omega^- \rightarrow \Xi^0 \pi^- \), and \( \Omega^- \rightarrow \Lambda K^- \), respectively. The index 4 refers to the total strong decay rates of \( \Xi^*^- \rightarrow \Xi \pi = \Xi^*^- \rightarrow \Xi^- \pi^0 + \Xi^*^- \rightarrow \Xi^0 \pi^- \).

| Decay          | Experiment   | Prediction | \( \chi^2 \) |
|---------------|--------------|------------|-------------|
| \( \Gamma_1(10^9 \text{seg}^{-1}) \) | 1.046 ± 0.051 | 1.241      | 14.64       |
| \( \alpha_1 \) | 0.05 ± 0.21  | 0.076      | 0.02        |
| \( \Gamma_2(10^9 \text{seg}^{-1}) \) | 2.871 ± 0.095 | 2.571      | 9.96        |
| \( \alpha_2 \) | 0.09 ± 0.14  | 0.078      | 0.01        |
| \( \Gamma_3(10^9 \text{seg}^{-1}) \) | 8.25 ± 0.15  | 8.247      | 0.0004      |
| \( \alpha_3 \) | −0.026 ± 0.026 | −0.021    | 0.04        |
| \( \Gamma_4(\text{MeV}) \)     | 9.9 ± 1.9    | 9.8        | 0.001       |
TABLE II. Predictions for the parity-conserving and parity-violating amplitudes in Ω\(^-\)
two-body non-leptonic decays assuming isospin symmetry limit and not assuming it. The per-
cent variations are with respect to the symmetry limit values. The indices are as in Table I.

| Decay | SU(2) symmetry | SU(2) symmetry | % variation |
|-------|----------------|---------------|-------------|
|       | (10\(^{-9}\)MeV\(^{-1}\)) limit | breaking |             |
| B\(_1\) | −0.8889 | −0.8175 | −8.0 |
| C\(_1\) | −0.3138 | −0.3098 | −1.3 |
| B\(_2\) | 1.257 | 1.327 | +5.6 |
| C\(_2\) | 0.4438 | 0.4300 | −3.1 |
| B\(_3\) | 4.014 | 4.015 | +0.02 |
| C\(_3\) | −0.4392 | −0.4259 | −3.0 |