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The Production Percentages of $L = 1$ Baryons in e^+e^- Annihilation

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We use a simple decay model for the lowest excited baryons to evaluate their decay contributions to the ground states. We further input the experimental data $R_1 = \Xi(1530)/\Xi$, $R_2 = \Sigma(1385)/\Sigma(1385)$ and $R_3 = \lambda(1520)/\Sigma(1385)$ at $\gamma(1S)$ resonance and use the basic relations derived in the previous paper to determine the total production rates of the lowest excited baryons of various $SU_f(3)$ multiplets.

Key words: hadronization, spin suppression, flavor conservation, excited baryons.

1. INTRODUCTION

All of the current fragmentation models, including the most popular Lund model, do not consider the production of excited baryons. However they should not be neglected in production due to the experimental fact by ARGUS that the multiplicity of singlet $\Lambda(1520)$ is rather high [1].

The basic relations given in [2] makes it possible to determine production percentages of excited baryons by inputting proper data. Because the produced excited baryons are mainly lower excited states, as the first order approximation, we only take the lowest excited states, i.e., $L = 1$ states into account to extract production percentages of the lowest excited decuplet, octet and singlet baryons [2] from the available data.

In order to determine production percentages of $L = 1$ baryons, we must estimate their decay contributions to ground states. However up to now there have been no enough branch ratio data for excited baryons (even the lowest excited states) in PDG [3]. We adopt a simple decay model in Sec. 2

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for the lowest excited baryons to estimate their average branch ratios and hence decay contributions to ground states. By using this decay model in Sec. 3, we calculate decay contributions from $L = 1$ baryons to $\Sigma^+(1385)$, Σ^+, $\Xi^0(1530)$ and Ξ^0 and input the experimental data $R_1 = \Xi(1530)/\Xi$, $R_2 = \Sigma(1385)/\Sigma$ and $R_3 = \Lambda(1520)/\Sigma(1385)$ at $\gamma(1S)$ resonance to determine production percentages of the lowest excited baryons.

The same as in [2], the ground state decuplet and octet baryons are denoted by 10 and 8, while those of excited states by 10′ and 8′; because all singlet baryons are excited, so they are denoted by 1′; their corresponding weights by P_{10}, P_8, $P_{10'}$, $P_{8'}$ and $P_{1'}$ respectively. Also denote percentages of 8′, 10′ and $\Lambda(1520)$ in the total primarily produced octet, decuplet and singlet baryons by $x_{8'} \equiv P_{8'}/(P_{8'} + P_8)$, $x_{10'} \equiv P_{10'}/(P_{10'} + P_{10})$ and $x_{\Lambda(1520)} \equiv P_{\Lambda(1520)}/P_{1'}$.

2. A SIMPLIFIED $SU_f(3)$ DECAY MODEL FOR $L = 1$ BARYONS

The experimental studies on decays of excited baryons (even for the lowest excited states) are very rudimentary. Many of the decay channels and branch ratios listed in PDG are not exact enough. There are lots of strange baryons in $(70, 1_{1-})$ multiplet whose identities are even not recognized. This is a large barrier for us to calculate their decay contributions to ground state baryons. We have to draw some decay characteristics of $L = 1$ baryons from present PDG data adopt a simple $SU_f(3)$ decay model to summarize an approximate spectrum of their major branch ratios.

From PDG, we see that most of the decay channels of excited baryons are $SU_f(3)$ allowed 2-body or quasi-2-body decays and most of their decay products are 8 or 10 baryons and 0^- mesons. The fraction of decaying into 1^- meson is small and might be omitted for simplification. We also see that strange baryons of $L = 1$, either 8′ or 10′ ones, which carry the same strangeness number have near masses.

The following is the decay model based on the above characteristics. For an $SU_f(3)$ allowed 2-body decay, X → Y + Z, the decay width and the branch ratio are (see [4] for details)

$$\Gamma^{X}_{YZ} = \|A^{X}_{YZ}\|^2 (p/m)^{2l} (p/m) M \tag{1}$$

where $\|A^{X}_{YZ}\|^2$: $Su_f(3)$ factor; $(p/m)^{2l}$: Barrier factor; $(p/m)M$: Phase space factor

$$f^{X}_{YZ} = \Gamma^{X}_{YZ}/\Gamma_{tot} = \Gamma^{X}_{YZ} \Big/ \sum_{Y,Z} \Gamma^{X}_{YZ} \tag{2}$$

where X is a 8′ or 10′ baryon of $L = 1$, Y is a 8 or 10 baryon and Z a 0^- meson; A^{X}_{YZ} is the $SU_f(3)$ symmetry factor, m the mass of the mother particle, p the momentum of the decay products (Y or Z) and M a free parameter (of about 1 GeV). Here we make two approximations for (1) and (2).

(1) We assume the barrier factor in (1) is a constant. Since the baryons with $L = 1$ have negative parity and decay to a ground state baryon and a 0^- meson, according to the parity conservation, the partial wave rank number l must be even. When $p \ll m$, i.e., the momentum of the decay products is very small compared to the mass of the decaying particle, the barrier factor decreases drastically at higher l. The few decay channels listed in PDG are mostly s- and d- waves, almost no higher partial waves exist. This assumption in fact means that we take only the lowest partial wave into account.

(2) We assume all of the $L = 1$ baryons which contain the same number of strange quarks or anti-strange quarks have the same mass. This assumption agrees well with the characteristic of $L = 1$ baryons as stated earlier. In the lowest approximation, a baryon is treated as an excited spectrum of

Table 1
The average masses of $L = 1$ baryons (i.e., baryons of multiplet 70, 1_{1-}).

8′ baryon $\bar{m}$ (MeV)	N′ 1607	$\Lambda_{8'}$ 1757	$\Sigma_{8'}$ 1757	$\Xi_{8'}$ 1907
10′ baryon $\bar{m}$ (MeV)	$\Delta_{10'}$ 1607	$\Sigma_{10'}$ 1757	$\Xi_{10'}$ 1907	$\Omega_{10'}$ 2057

two uncoupled 3-dimensional harmonic oscillators [5]. Therefore the mass can be written by $M = M_0 + \omega N$, where $N = 2(n_\lambda + n_\rho) + l_\lambda + l_\rho$, with n_λ and n_ρ the radical excited quantum number, $L = l_\rho + l_\lambda$ is the orbit excited quantum number, $M_0 = m_1 + m_2 + m_3 +$ const, here m_i is the constituent quark mass for quark i. So the mass spectra of $N = L = 1$ baryons containing the same number of strange quarks or antiquarks are degenerate. We take $m_s - m_U = 150$ MeV, $m_{\Delta',N'} = 1607$ MeV, then the values of $m_{\Delta'}$, $m_{\Sigma'}$, $m_{\Xi'}$, $m_{\Omega'}$ are listed in Table 1, where (′) marks excited states.

After using these approximations, we finally derive branch ratios of all 8′ and 10′ baryons, which are shown in Tables 2(a) and 2(b), where f_i is the average weight for a certain baryon $i \in 8'$ to decay into 8, while $(1 - f_i)$ the one for it to decay into 10; so is $f_{i'}$ for $i \in 10'$. One thing which should be noted is that the branch ratios in Tables 2(a) and 2(b) are the average of all corresponding $(70, 1_{1-})$ multiplets for each 8′ or 10′ member. For instance, baryon $\Sigma_{8'}$ is the average of Σ members of octets from all $(70, 1_{1-})$ multiplets i.e., $J^P_{2S+1} = (1/2)^-_2, (3/2)^-_2, (1/2)^-_4, (3/2)^-_4, (5/2)^-_4$ one. The comparison with PDG shows these ratios agree approximately with the existing data for those identified baryons.

3. THE PRODUCTION PERCENTAGES OF $L = 1$ BARYONS OF VARIOUS $SU_f(3)$ MULTIPLETS

In this section, we try to use the average branch ratios of $L = 1$ excited states given in Tables 2(a) and 2(b) to determine the production percentages of $L = 1$ baryons of various $SU_f(3)$ multiplets. To avoid more complexity, consider a simple case that the average weights with which strange 8′ and 10′ baryons decay into 8 are equal to each other, i.e., $f_i = f$ for $i = (\Sigma_{8'}, \Lambda_{8'}, \Xi_{8'})$ and $f_{i'} = f'$ for $i = (\Sigma_{10'}, \Xi_{10'}, \Omega')$, where f_i is the average weight for a certain baryon $i \in 8'$ to decay into 8, while $(1 - f_i)$ the one for it to decay into 10; so is $f_{i'}$ for $i \in 10'$. The approximation is necessary to reduce the number of unknown parameters and make it possible for us to reach the destination when we know only a little about branch ratios for $L = 1$ baryons. In a sense, it can approximately reflect dependence of any $X_{k'}$s ($k' = 8'$, 10′ and $\Lambda(1520)$) on decay contributions from excited states.

After taking all members of excited $SU_f(3)$ multiplets, which contribute to Ξ or Σ, into account, their production weights can be written as

$$W_{B=\Xi,\Sigma} = P_8\lambda^r + P_{10}\sum_{a\in 10}\lambda^{r_a}B_r(a\to B) + fP_{8'}\left[\sum_{a'\in 8'}\lambda^{r_{a'}}\bar{B}_r(a'\to B) + \sum_{a'\in 8', a\in 10}\lambda^{r_{a'}}\bar{B}_r(a'\to a)B_r(a\to B)\right]$$

$$+ f' P_{10'} \Big[\sum_{a' \in 10'} \lambda^{r_{a'}} \bar{B}_r(a' \to B)$$

$$+ \sum_{a' \in 10', a \in 10} \lambda^{r_{a'}} \bar{B}_r(a' \to a) B_r(a \to B) \Big]$$

$$+ P_{1'} \sum_{a' \in 1'} \lambda^{r_{a'}} \bar{B}_r(a' \to B) \tag{3}$$

For $\Xi(1530)$ and $\Sigma(1385)$, the weights are

$$W_{B=\Xi(1530),\Sigma(1385)} = P_{10}\lambda^r + (1-f) P_{8'} \sum_{a' \in 8'} \lambda^{r_{a'}} \bar{B}_r(a' \to B)$$

$$+ (1-f') P_{10'} \sum_{a' \in 10'} \lambda^{r_{a'}} \bar{B}_r(a' \to B) \tag{4}$$

When r denotes the number of strange quarks (or anti-strange quarks for an antibaryon), i.e., the strangeness number which (Ξ,Σ) and $(\Xi(1530),\Sigma(1385))$ contain, respectively. a denotes a 10 or 8 member, while r_a is its strangeness number. a$'$ denotes a 10$'$ or 8$'$ member, while $r_{a'}$ is its strangeness number. $\sum_{a' \in 8'}$ is to sum all of the members from 8$'$, which contribute to (Ξ,Σ) and $(\Xi(1530),\Sigma(1385))$. Other sum marks have the similar meaning. $\bar{B}_r$ is the average branch ratio from Tables 2(a) and 2(b), while B_r from PDG.

The production weight of $\Lambda(1520)$ is,

$$W_{\Lambda(1520)} = x_{\Lambda(1520)} P_{1'} \lambda \tag{5}$$

Take ratios of $\Xi(1530)$ to Ξ, $\Sigma(1385)$ to Σ and $\Lambda(1520)$ to $\Lambda(1385)$ as follows

$$\begin{cases} R_1 = W_{\Xi(1530)}/W_{\Xi} \\ R_2 = W_{\Sigma(1385)}/W_{\Sigma} \\ R_3 = W_{\Lambda(1520)}/W_{\Sigma(1385)} \end{cases} \tag{6}$$

Take experimental data at γ resonance energy (γ^{on}) by ARGUS as the input of Eq.(6):

$$\begin{cases} R_{1,exp} = 0.232 \pm 0.057 \pm 0.035 \\ R_{2,exp} = 0.275 \pm 0.090 \pm 0.065 \\ R_{3,exp} = 0.92 \pm 0.21 \pm 0.16 \end{cases} \tag{7}$$

Then, we use the basic relations and obtain

$$\begin{cases} \dfrac{1}{0.232} = 1 + \dfrac{2.1 + (0.492f - 1)\rho + (2 + 0.58f')\sigma}{1 + 0.69(1-f)\rho + 0.512(1-f')\sigma} \\ \dfrac{1}{0.275} = 0.12 + \dfrac{2.16 + (0.856f - 1.126)\rho + (2.19 + 0.52f')\sigma}{1 + 0.72(1-f)\rho + 0.8(1-f')\sigma} \\ 0.92 = \dfrac{x_{\Lambda(1520)}(1+\sigma)}{1 + 0.72(1-f)\rho + 0.8(1-f')\sigma} \end{cases} \tag{8}$$

where we take $\lambda = 0.3$ and $\sigma \equiv P_{10'}/P_{10}$, $\rho \equiv P_{8'}/P_{10}$, so $x_{8'} = \rho/2(1+\sigma)$, $x_{10'} = \sigma/(1+\sigma)$. $x_{\Lambda(1520)}$ is the production percentage of $\Lambda(1520)$ in all singlet baryons with $L = 1$.

Table 2(a)

The average branch ratio (BR) of 8′ baryons decaying into 8 and 10 ones calculated from the simplified decay model for L = 1 baryons.

$i \to B_8P$	Branch ratio/f_i	$i \to B_{10}P$	Branch ratio/$(1-f_i)$
$N \to N\pi$	0.987	$N' \to \Delta(1232)\pi$	1.0
$\to \Lambda K$	0.013		
$\Lambda_{8'} \to NK$	0.337	$\Lambda_{8'} \to \Sigma(1385)\pi$	1.0
$\to \Sigma\pi$	0.554		
$\to \Lambda\eta$	0.109		
$\Sigma_{8'} \to \Sigma\pi$	0.475	$\Sigma_{8'} \to \Sigma(1385)\pi$	0.333
$\to \Lambda\pi$	0.161	$\to \Delta(1232)K$	0.667
$\to NK$	0.365		
$\Xi_{8'} \to \Xi\pi$	0.492	$\Xi_{8'} \to \Sigma(1385)K$	0.31
$\to \Lambda K$	0.174	$\to \Xi(1530)\pi$	0.69
$\to \Sigma K$	0.333		

Table 2(b)

The average branch ratio (BR) of 10′ baryons decaying into 8 and 10 ones calculated from the simplified decay model for L = 1 baryons.

$i \to B_8P$	Branch ratio/f_i	$i \to B_{10}P$	Branch ratio/$(1-f_i)$
$\Delta' \to N\pi$	1.0	$\Delta' \to \Delta(1232)\pi$	1.0
$\Sigma_{10'} \to NK$	0.26	$\Sigma_{10'} \to \Sigma(1385)\pi$	0.67
$\to \Sigma\pi$	0.33	$\to \Delta(1232)K$	0.33
$\to \Lambda\pi$	0.407		
$\Xi_{10'} \to \Xi\pi$	0.43	$\Xi_{10'} \to \Sigma(1385)K$	0.638
$\to \Lambda K$	0.307	$\to \Xi(1530)\pi$	0.362
$\to \Sigma K$	0.262		
$\Omega' \to \Xi K$	1.0	$\Omega' \to \Xi(1530)K$	1.0

$$\begin{cases} 1.21 = (2.772f - 3.28)\rho + (2.274f' + 0.306)\sigma \\ 1.36 = (3.39f - 3.66)\rho + (3.33f' - 0.623)\sigma \end{cases} \tag{9}$$

and

$$x_{\Lambda(1520)} = 0.92(1 + 0.72(1 - f)\rho + 0.8(1 - f')\sigma)/(1 + \sigma) \tag{10}$$

Since the only two singlet members for L = 1 states, i.e., Λ(1520) and Λ(1405), we can thus derive the multiplicity of Λ(1405) from Eq.(10) as

$$n_{\Lambda(1405)} = n_{\Lambda(1520)}(1 - x_{\Lambda(1520)})$$

Table 3

$x_{8'}$, $x_{10'}$, $x_{\Lambda(1520)}$ and the multiplicity of $\Lambda(1405)$, $n_{\Lambda(1520)}$.

f' \ f	0.7	0.8	0.9	1.0
0.7	0.0 0.0 0.92 0.001	0.82 0.95 0.47 0.013	0.50 0.64 0.54 0.0099	0.36 0.51 0.57 0.0088
0.8	0.0 0.0 0.92 0.001	0.47 0.66 0.53 0.010	0.33 0.52 0.56 0.0089	0.25 0.44 0.58 0.0083
0.9	0.39 0.63 0.54 0.0098	0.28 0.51 0.57 0.0088	0.21 0.43 0.58 0.0083	0.18 0.39 0.59 0.008
1.0	0.21 0.46 0.58 0.0085	0.16 0.41 0.59 0.0081	0.13 0.37 0.59 0.0079	0.11 0.35 0.60 0.0077

We can solve Eq.(9) and obtain σ and ρ functions of f and f'. Because $\sigma, \rho \geq 0$, we can see that Eq.(9) has no physical solutions when $f < 0.5$ or $f' < 0.4$. When $0.4 \leq f' \leq 0.7$ ($0.5 \leq f \leq 0.7$), the physical solutions exist only if $f \to 1$ ($f' \to 1$). It shows that the calculation is reasonable only if strange $8'$ and $10'$ baryons mainly decay into 8 ones, which is approximately consistent with the tendency of PDG's existing data [3] about $L = 1$ baryons.

Listed in Table 3 are values of $x_{8'}$, $x_{10'}$, $x_{\Lambda(1520)}$ and $n_{\Lambda(1520)}$ at various (f, f') when $f, f' \geq 0.7$. We can see from the table that the results depend on the values of f and f' sensitively.

4. CONCLUSIONS

The current work is an application of [2]. We have discussed in [2] the consistency of the $SU_f(3)$ symmetry and the requirement of the flavor conservation under the stochastic quark combination scheme (SQCS). This two properties lead to the basic relations which are general restrictions on production weights of various $SU_f(3)$-plets in the SQCS. The basic relations can be applied not only to hadronization processes in e^+e^- annihilation but also other ones in h-h or l-h interactions.

The basic relations make it possible to determine the abundance of excited baryons of various $SU_f(3)$ multiplets by inputting suitable data. Since there is only a little decay information for excited baryons provided by experiments at present, we have to build a simple $SU_f(3)$ decay model for excited states to evaluate their contributions to ground ones. In this way, we finally determine the production percentages of excited octet, decuplet and singlet $\Lambda(1520)$. Although the uncertainties brought by errors of the three inputs are substantially large, this method is quite general. It is obvious that one can derive more accurate prediction when experimental data have smaller errors. The multiplicity of $\Lambda(1405)$ might be easier to be measured than other excited baryons, therefore we give its prediction at γ^{on} in particular.

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