Lifetime pattern of heavy hadrons

B. Guberina, B. Melić and H. Štefančić
Theoretical Physics Division, Rudjer Bošković Institute,
P.O.Box 180, HR-10002 Zagreb, Croatia
E-mails: guberina@thphys.irb.hr, melic@thphys.irb.hr,
shrvoje@thphys.irb.hr

Abstract
We discuss the lifetime pattern of weakly decaying heavy hadrons.

Talk given by B. Melić at The 30th International Conference on High
Energy Physics, July 27 - August 2, 2000, Osaka, Japan
To appear in the Proceedings
LIFETIME PATTERN OF HEAVY HADRONS

B. GUBERINA, B. MELIĆ AND H. ŠTEFANČIĆ

Theoretical Physics Division, Rudjer Bošković Institute,
P.O.Box 180, HR-10002 Zagreb, Croatia
E-mails: guberina@thphys.irb.hr, melic@thphys.irb.hr, shrvoje@thphys.irb.hr

We discuss the lifetime pattern of weakly decaying heavy hadrons.

1 Introduction

A lot of physical observables in heavy-quark decays are described using the inverse heavy-quark mass expansion in terms of a few basic quantities, i.e., quark masses and hadronic expectation values of several local operators. The remarkable fact that the expansion is applicable even to the charmed case enables one to connect charmed and beauty sectors. In this presentation we relate lifetimes of heavy hadrons and obtain some interesting predictions.

Large lifetime differences between charmed hadrons, shown in Fig. 1, cannot be explained by taking just $O(1/m_c^2)$ corrections into account. The diversity among charmed hadron lifetimes is attributed to the effects of four-quark operator ($O^{4q}$) contributions of the order of $1/m_c^3$. For charmed mesons and baryons, the theoretical findings have been also confirmed by experiment. Analogously, a significant spread of doubly charmed baryon lifetimes is predicted, Fig. 1.

For beauty hadron decays there is a rapid convergence of the $1/m_b$ expansion and the leading $O(1/m_b^2)$ corrections introduce a difference of just $2-3\%$ between lifetimes of beauty hadrons. But, owing to the peculiarity of the $1/m_Q$ expansion, exhibited also in charmed decays, there is still some place for $O(1/m_Q^2)$ operators to play a significant role in beauty decays. In a recent work we have found an enhancement of the $O^{4q}$ contributions in beauty baryon decays. Such an enhancement brings the $\tau(\Lambda_b)/\tau(B)$ ratio much closer to the experimental value compared with the standard nonrelativistic-model estimation and predicts a much larger spread among beauty-baryon lifetimes, Fig. 2.

\textsuperscript{a} Talk given by B. Melić at ICHEP2000, July 27 - August 2, Osaka, Japan
2 Connecting charm and beauty

As in the calculation of the $O^{4q}$ contributions one relies on the questionable nonrelativistic models, it is a challenge to search for some model-independent determination of such contributions. Having in mind the same formalism applied in the treatment of both charmed and beauty decays, and large effects which the $O^{4q}$ contributions exhibit in the lifetimes of charmed as well as beauty hadrons, discussed in Sec. 1, we try to perform a model-independent analysis searching for an explicit connection between charmed and beauty sectors.

Similar ideas have already been applied, first by Voloshin to obtain the lifetime differences between beauty hyperons, and then by us, where we have obtained, in a moderate model-dependent analysis, an enhancement of four-quark contributions for beauty baryons with predictions shown in Fig. 2. We group heavy hadrons exhibiting the same type of $O^{4q}$ contributions in pairs and consider their decay-rate differences applying the SU(2) isospin symmetry and the heavy-quark symmetry (HQS). Cabibbo suppressed modes and mass corrections in final states are neglected. We start our investigation by treating
different heavy-hadron sectors separately.

2.1 Heavy mesons

The first pair of considered mesons form $D^+$ and $B^-$. In decays of both of these mesons the negative Pauli interference occurs. The second pair of particles having the effects of a weak exchange form $D^0$ and $B^0$. The idea is to combine decay rates in such a manner that the effects of the $O^{4q}$ contributions are isolated:

$$\Gamma(D^+) - \Gamma(D^0) = \frac{G_F^2 m_c^2}{4\pi} |V_{cs}|^2 |V_{ud}|^2 \times$$
$$\left[ \langle D^+ | L^{4q}_{4q} | D^+ \rangle - \langle D^0 | L^{4q}_{4q} | D^0 \rangle \right]$$

$$\Gamma(B^-) - \Gamma(B^0) = \frac{G_F^2 m_b^2}{4\pi} |V_{cb}|^2 |V_{ud}|^2 \times$$
$$\left[ \langle B^- | L^{4q}_{4q} | B^- \rangle - \langle B^0 | L^{4q}_{4q} | B^0 \rangle \right].$$
\(\mathcal{L}\)'s are parts of the weak Lagrangian involving Cabibbo-leading nonleptonic as well as semileptonic parts.

Assuming the isospin symmetry in the heavy-quark limit, the \(O^{4s}\) contributions get reduced and we obtain the following relation:

\[
R^{BD} = \frac{\Gamma(B^-) - \Gamma(B^0)}{\Gamma(D^-) - \Gamma(D^0)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2} [1 + O(1/m_{b,c})].
\]

Starting from this expression, we may check the standard formalism of inclusive decays, expressed by Eq. (1), against experimental data on heavy-meson lifetimes \[8\]. The results are

\[
R^{BD} = 0.020 \pm 0.007,
\]

\[
R^{BD}_{\text{exp}} = 0.030 \pm 0.011,
\]

and they are consistent within errors.

2.2 Heavy baryons

In baryon decays we find \(\Xi^+\) and \(\Xi^0\) experiencing the negative interference, and \(\Xi_0^c\) and \(\Xi_0^b\) exhibiting the weak exchange. There are also different nonleptonic and semileptonic contributions from the operators involving s-quark, but they cancel in the decay-rate differences:

\[
\Gamma(\Xi^+_{c}) - \Gamma(\Xi^0_{c}) = \frac{G_F^2 m_c^2}{4\pi} |V_{cs}|^2 |V_{ud}|^2 \times
\]

\[
\left[ (\Xi^+_c |\mathcal{L}_P^{\text{PI}}| \Xi^+_c) - (\Xi^0_c |\mathcal{L}_P^{\text{exc}}| \Xi^0_c) \right]
\]

\[
\Gamma(\Xi^-_{b}) - \Gamma(\Xi^0_{b}) = \frac{G_F^2 m_b^2}{4\pi} |V_{cb}|^2 |V_{ud}|^2 \times
\]

\[
\left[ (\Xi^-_b |\mathcal{L}_P^{\text{PI}}| \Xi^-_b) - (\Xi^0_b |\mathcal{L}_P^{\text{exc}}| \Xi^0_b) \right].
\]

Applying SU(2) symmetry and HQS as before, we obtain to order \(1/m_{c,b}\)

\[
R^{bc} = \frac{\Gamma(\Xi^-_{b}) - \Gamma(\Xi^0_{b})}{\Gamma(\Xi^+_c) - \Gamma(\Xi^0_c)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2}.
\]

This relation can serve as a test of the model-dependent predictions, presented in Figs.1 and 2. If we calculate \(R^{bc}\) using model-dependent approach \[3,5\] consistently with approximations made in this analysis, we obtain a difference of 12% compared with the prediction obtained from Eq. (2). By performing the complete calculation with the mass corrections and Cabibbo-suppressed
modes included, we can judge the order of neglected corrections to be less than 10%.

The relation (2) enables us to obtain a prediction for the lifetime difference between beauty hyperons, using measured lifetimes of singly-charmed baryons $\Xi^+_c$ and $\Xi^0_c$:

$$\Gamma(\Xi^+_c) - \Gamma(\Xi^0_c) = -(0.14 \pm 0.06) \text{ ps}^{-1}.$$  

The prediction can be compared with the values from 6 and 5, where SU(3)$_f$ symmetry and HQS were used. All results appear to be consistent with each other.

2.3 Doubly-heavy baryons

Finally, a similar procedure applies to doubly-heavy baryons. The obtained expression now relates doubly beauty baryons with doubly-charmed baryons to order $1/m_{c,b}$:

$$R^{bbcc} = \frac{\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0)}{\Gamma(\Xi_{cc}^{++}) - \Gamma(\Xi_{cc}^+)} = \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2}$$  

(3)

Unfortunately, there is still no experimental evidence for doubly-heavy baryon lifetimes to check the above relation. However, we can use it to calculate the splitting among doubly-beauty hyperons $\Xi_{bb}^-$ and $\Xi_{bb}^0$, by taking existing theoretical predictions for doubly-charmed lifetimes. The prediction for the doubly-beauty lifetime spread is

$$\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0) = -0.073 \text{ ps}^{-1}.$$  

3 Conclusions

By inspection of all three relations (1), (2) and (3) we can see that there exists a universal behavior in decays of heavy hadrons summarized by the expression:

$$\frac{\Gamma(B^-) - \Gamma(B^0)}{\Gamma(D^+) - \Gamma(D^0)} = \frac{\Gamma(\Xi_{bb}^-) - \Gamma(\Xi_{bb}^0)}{\Gamma(\Xi_{cc}^{++}) - \Gamma(\Xi_{cc}^+)} =$$

$$= \frac{m_b^2 |V_{cb}|^2}{m_c^2 |V_{cs}|^2}.$$

This relation connects all sectors of weakly decaying heavy hadrons that are usually treated separately: mesons and baryons, charmed and beauty particles, and brings some order in the otherwise rather intricate pattern of heavy-hadron lifetimes. The predictions we have obtained, although burdened with
some approximations, if experimentally confirmed would indicate that four-quark operators can account for the greatest part of the decay rate differences among heavy hadrons.

This work was supported by the Ministry of Science and Technology of the Republic of Croatia under the contract No. 00980102.

References

1. I. Bigi, hep-ph/0001003
2. B. Guberina, S. Nussinov, R.D. Peccei, R. Rückl, Phys. Lett. B 89, 111 (1979).
3. B. Guberina, B. Melić, Eur. Phys. J. C 2, 697 (1998).
4. B. Guberina, B. Melić, H. Štefančič, Eur. Phys. J. C 9, 213 (1999); Erratum, ibidem C 13 551 (2000).
5. B. Guberina, B. Melić, H. Štefančič, Phys. Lett. B 469, 253 (1999).
6. M.B. Voloshin, Phys. Rept. 320, 275 (1999).
7. B. Guberina, B. Melić, H. Štefančič, Phys. Lett. B 484, 43 (2000).
8. Partical Data Group, C. Caso et al, Eur. Phys. J. 1 C 3, 1 (1998).