Weak decays and life time of B_c meson

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Introduction

The B_c state is the only bound system that consists of two heavy quarks of different flavours that offers a sound laboratory opportunity to observe both QCD and weak interaction. The charmed bottom meson $c\bar{b}$ is an intermediate state of the $c\bar{c}$ mesons and $b\bar{b}$ mesons.

The investigation of masses gives us an opportunity to obtain information on the nature of the strong interaction thereby it throws up an interesting issue and a tantalising problem. The study of properties of $c\bar{b}$ states is of great importance since it consists of two heavy quarks of different flavour which forbid the annihilation decays to photon and gluon. Because of this uniqueness, the ground state of $c\bar{b}$ state which is below the BD threshold, can only decay through weak interaction and through radiative transition. This provides an ideal platform to study weak decays and provides new methods for calculating the CKM matrix.

Weak Decays

The weak decays of bound state of a quark and an anti-quark, which carries heavy flavour c and b - enable us to probe the validity of the standard model of elementary particle interactions and determine several parameters of this model. A rough estimate of the B_c weak decay widths can be done by treating the $\bar{b}$-quark and c-quark decay independently so that B_c decay can be divided into three classes: (i)the $\bar{b}$-quark decay with spectator c-quark, (ii) the c-quark decay with spectator $\bar{b}$-quark, and (iii) the annihilation $B_c^+ \rightarrow l^+\nu_l$ ($c\bar{s}$, $u\bar{s}$), where $l = e,\ \mu,\ \tau$. The total width is the sum over partial widths

$$\Gamma(B_c \rightarrow X) = \Gamma(b \rightarrow X) + \Gamma(c \rightarrow X) + \Gamma(ann) \quad (1)$$

In the spectator approximation:

$$\Gamma(\bar{b} \rightarrow X) = \frac{9G_F^2|V_{cb}|^2 m_b^5}{192\pi^3} \quad (2)$$

and

$$\Gamma(c \rightarrow X) = \frac{5G_F^2|V_{cs}|^2 m_c^5}{192\pi^3} \quad (3)$$

where V_{cb} and V_{cs} are the elements of the CKM matrix.
The leptonic partial widths are probe of the compactness of quarkonium system and provide important information complementary to level spacings. The quark-antiquark assignments for the vector mesons, as well as the fractional values for the quark charges, may be tested from the values of their leptonic decay widths. The decay of vector meson into charged leptons proceeds through the virtual photon ($q\bar{q} \rightarrow l^+l^-$). The $^3S_1$ and $^3D_1$ states have quantum numbers of a virtual photon, $J^{PC} = 1^{--}$ and can annihilate into lepton pairs through one photon. Annihilation widths such as $c\bar{b} \rightarrow l\nu_l$ are given by the expression

$$\Gamma(ann) = \frac{G_F^2}{8\pi}|V_{bc}|^2 f_{B_c}^2 M_{B_c} \sum_i m_i^2 \left(1 - \frac{m_i^2}{M_{B_c}^2}\right) C_i \quad (4)$$

where m_i is the mass of the heavier fermion in the given decay channel. For lepton channels $C_i = 1$ while for quark channels $C_i = 3|V_{q\bar{q}}|^2$.

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The pseudo scalar decay constant f_{B_c} is defined by [1]:

$$\langle 0|\bar{b}(x)\gamma^{\mu}c(x)|B_c(k)\rangle = if_{B_c}V_{cb}k^{\mu} \quad (5)$$

where k^{μ} is the four-momentum of the B_c meson. In the non relativistic limit the pseudo scalar decay constant is proportional to the wave function at the origin and is given by van Royen-Weisskopf formula [2]

$$f_{B_c} = \sqrt{\frac{12}{M_{B_c}}}\psi(0) \quad (6)$$

Results and Conclusion

We have calculated the weak decay widths and life time τ of B_c meson in the spectator approximation using equations 2,3 and 4. We use the following set of parameter values.

$$\begin{aligned} m_c = 1.48 \quad \text{GeV}; \quad m_b = 4.740 \text{ GeV}; \\ b = 0.325 \text{ fm}; \quad \alpha_s = 0.3, \quad |V_{cs}| = 0.975; \\ a_c = 157.5 \text{ MeV fm}^{-1}, \quad |V_{bc}| = 0.044; \\ M_{B_c} = 6.277 \quad \text{GeV}; \end{aligned} \quad (7)$$

From equation (2) we have,

$$\Gamma(\bar{b} \to X) = 9.527 \times 10^{-4} \text{ eV}$$

Equation (3) gives

$$\Gamma(c \to X) = 7.71 \times 10^{-4} \text{ eV}$$

and equation (4) gives

$$\Gamma(\text{ann}) = 0.864 \times 10^{-4} \text{ eV}$$

Adding these results we get the total decay width $\Gamma(\text{total}) = 18.104 \times 10^{-4}$ eV corresponding to a B_c life time of $\tau = 0.364$ ps which is in good agreement with the experimental value $\tau = 0.452 \pm 0.033$ ps. The value of decay constant in the non relativistic potential model are listed in Table II

Acknowledgments

One of the authors (APM) is grateful to BRNS, DAE, India for granting the project and JRF (37(3)/14/21/2014BRNS).

TABLE I: **Comparison of life time of B_c meson (in ps).**

This work	Exp.[3]	[4]	[5]	[6]	[7]
0.362	0.452±0.033	0.47	0.55±0.15	0.50	0.75

TABLE II: **Comparison of predictions for the pseudo scalar decay constant of the B_c meson.**

Parameter	[8]	[9]	[10]	[11]	This work
f_{B_c}	500	512	479	440±20	439.691

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