Branching Ratios of B_c Mesons – Radiative Decay

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Introduction

Theoretical and experimental studies of the heavy quark sector in the Standard Model are of a great interest to complete the whole quantitative picture of fundamental interactions.

In the bottom quark physics experimentalists step from the 10^6 yield of hadrons containing b-quark at present facilities up to the 10^9 yield in the foreseeable future to measure rare processes like the CP-violation and possible effects beyond the SM. To distinguish the hadronic dynamics from the latter effects at the quark level one needs the perfect understanding of QCD interactions binding the quarks into hadrons [1].

One of the accompanying problem is the observation and study of the $(\bar{b}c)$ state, yielding a 10^{-3} fraction of beauty hadrons at high energies.
The B_c meson allows one to accomplish the QCD-based models of hadrons with the bottom quarks, one to study the specific production and decay mechanisms and one to measure the SM parameters.

The basic state of B_c is the long-lived heavy quarkonium, which can be searched for in a way analogous to the observation of beauty mesons with a light quark [2]. At CDF the background is still strong to isolate the B_c event at low statistics available [3]. At present, the LEP Collaborations have reported on several candidates for the Be decays [4]. B_c is a long-living particle, decaying due to weak interaction. On the other hand, B_c consists of heavy quarks, and, therefore, it can be reliably described by the use of methods developed for the $(\bar{c}c)$ charmonium and the $(\bar{b}b)$ bottomonium.

Theoretical Background

Electric dipole (E1 Transitions):
The partial width for electric dipole (E1) transitions is given by

$$\Gamma_{i\to f+\gamma} = (2J'+1)\frac{4}{3}Q_b^2\alpha k_0^3 S_{if}^E\left|\varepsilon_{if}\right|^2$$

Magnetic dipole (M1 transitions)

$$\Gamma_{a\to b+\gamma} = \delta_{La\,Lb}4\alpha k_0^3\frac{E_b(k_0)}{m_a}\left(\frac{Q_c}{m_c} + (-1)^{S_a+S_b}\frac{Q_{\bar{b}}}{m_b}\right)^2(2S_a+1)$$

The bright feature of the $(\bar{b}c)$ family is that there are no annihilation decay modes due to the strong interaction. So, the excitations, in a cascade way, decay into the ground state with the emission of photons and pion -pion pairs.
The formulae for the E1- transitions are slightly modified

$$\Gamma(\bar{n}P_J \to n^1S_1+\gamma) = \frac{4}{9}\alpha_{em}Q_{eff}^2\omega^3\, I^2(\bar{n}P;nS)\omega_J(\bar{n}P),$$

$$\Gamma(\bar{n}P_J \to n^1S_0+\gamma) = \frac{4}{9}\alpha_{em}Q_{eff}^2\omega^3 I^2(\bar{n}P;nS)(1-\omega_J(\bar{n}P))$$

Where ω is the photon energy α_{em} is the electromagnetic fine structure constant. In the above equation, one uses

$$Q_{eff} = \frac{m_c Q_{\bar{b}} - m_b Q_c}{m_c + m_b}$$

Where $Q_{c,b}$ are the electric charges of the quarks. For the B_c meson with the parameters from the Martin potential, one gets $Q_{eff} = 0.41$. $\omega_J(nL)$ is the probability that the spin S = 1 in the nL state. $S_{JJ'}$ are the statistical factors.

Results and Discussions

The approaches, developed to describe emission by the heavy quarks, have been applied to the description of the radiative transitions in the ($\bar{b}$c) family, whose states have no electromagnetic or gluonic channels of annihilation. The last fact means that, due to the cascade processes with the emission of photons and pion pairs, the higher excitations decay into the lightest pseudoscalar B_c meson, decaying in the weak way. Therefore, the ground states of the ($\bar{b}$c) system have the widths, essentially high than those in the heavy quark meson systems

Table 1: E1 Transition rates of B_c meson

Transition $i \rightarrow f$ (keV)	**K (keV)**	**Present work Γ $i \rightarrow f$ (keV)**
$1P_1 \rightarrow 1^3S_1\gamma$	329.71	49.438
$1P_1 \rightarrow 1^1S_0\gamma$	411.23	31.974
$2^3S_1 \rightarrow 1^3P_0\gamma$	258.92	7.98
$2^3S_1 \rightarrow$ 1Pγ	210.43	8.568
$2^3S_1 \rightarrow 1P'\gamma$	162.42	3.939
$2^3S_1 \rightarrow 1^3P_2\gamma$	159.59	6.228

Table 2: Decay width ratio of E1 transitions

Initial State	**Present work Γ (keV)**	**Γ_{total} (keV)**	**$\frac{\Gamma}{\Gamma_{total}}$**
$1P_1$	31.974	82	0.389
2^3S_1	8.568	14.74	0.581

Conclusions

In nonrelativistic quark model (NRQM) formalism though, the mass spectra of the ground state $c\bar{b}$ meson has been produced successfully; the radiative decay rates. Therefore, it is necessary to include these effects for the correct description of the decays. Radiative decays are the most sensitive to relativistic effects. Hindered radiative decays are forbidden in the nonrelativistic limit due to the orthogonality of the initial and final meson wave functions. They have decay rates of the same order as the allowed ones. In the relativistic description of mesons, an important role is played by the confining quark-antiquark interaction, particularly its Lorentz structure. The dominant multipole transitions El have been studied and this helps us to extract information about new meson states and discover them. Radiative transitions are very important and interesting because the charge structure of the mesons and their quantum numbers can be determined through these transitions. We consider El radiative transitions non-relativistically for B_c meson states. Wave function effects also play a major role in determining decay widths

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