Radiative Decays of D and D_s Mesons in NRQM with OGEP *

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Introduction

The mass spectrum of D and D_s states are obtained in a phenomenological NRQM, which consists of a confinement potential and OGEP as effective quark-antiquark potential. Study of hadronic decay properties is another equally important area of research in the field of hadron physics and phenomenological particle physics. The experimental detection of heavier mesons with heavy flavour combinations have opened up a vast data bank for the hadronic decays into various channels. Radiative decays of excited charmonium states are a powerful tool to study the internal structure of the mesons. The quarkonium is studied using usual multipole expansion to compute the transition between the quarkonia states with the emission of a photon. The lowest order of multipole expansion dominates the transition. The resulting transitions are the magnetic dipole M_1 and the electric dipole E_1 transitions. In a M_1 transition only the spin of the quarkonium state is changed, while the parity and the orbital angular momentum remain unchanged. The expression for the decay width of a spin-flip M_1 transition between heavy quarkonium states depend on the radial matrix element. The different radial matrix elements can be obtained from the corresponding spin-flip magnetic moment operator. In electric dipole E_1 transition, the parity of the states changes while spin remains unchanged. Radiative transitions play an important role in the discovery and identification of quarkonium states. They are sensitive to the internal structure of states, in particular to ${}^3L_L - {}^1L_L$ mixing for states with J = L.

Theoretical Background

For the investigation of quarkonium states we have taken E_1 and M_1 radiative transitions since the higher-order transitions contribute little to the radiative decays. The $M1$ decay width for the transition $n\ {}^{2S+1}L_{J_i} \to n'\ {}^{2S'+1}L_{J_f} + \gamma$ is given by [1],

$$\Gamma_{M1}(a \to b+\gamma) = \frac{16}{3}\alpha\mu_{eff}^2 k_0^3(2J_b+1) \left[\int_0^\infty R_{n_bL_b}(r) r^2 R_{n_aL_a}(r) dr\right]^2 \quad (1)$$

where $\int_0^\infty dr R_{n_bL_b}(r) r^2 R_{n_aL_a}(r)$ is the overlap integral for unit operator between the coordinate wave functions of the initial and the final meson states. The m_a and m_b are the masses of the quark and antiquark and $\mu_{eff}^2 = \frac{m_aQ_b - m_bQ_a}{4m_am_b}$. The S_a, S_b, L_a, J_a and J_b are spin, orbital angular momentum and total angular momentum quantum numbers of initial and final meson states respectively. The M1 transitions contribute little to the total decay widths of the 2S levels. Allowed M1 transitions correspond to triplet-singlet transitions between S-wave states of the same n quantum number, while hindered M1 transitions are either triplet-singlet or singlet-triplet transitions between S-wave states of different n quantum numbers. The M1 transitions are essentially $1\ {}^3S_1 \to 1\ {}^1S_0$ and $2\ {}^3S_1 \to 1\ {}^1S_0$.

In electric dipole ($E1$) transitions, the parity of the states changes while spin remains unchanged. The $E1$ transition width for the decay $n\ {}^{2S+1}L_{iJ_i} \to n'\ {}^{2S+1}L_{fJ_f} + \gamma$ is given by [1],

$$\Gamma_{a\to b} = \frac{4\alpha}{9}\mu^2\left(\frac{Q_a}{m_a} - \frac{Q_b}{m_b}\right)^2 \frac{E_b(k_0)}{m_a} k_0^3 |\langle R_b|r|R_a\rangle|^2 \begin{cases} (2J+1)/3, & {}^3S_1 \to {}^3P_J \\ 1/3, & {}^3P_J \to {}^3S_1 \\ 1/3, & {}^1P_1 \to {}^1S_0 \\ 1, & {}^1S_0 \to {}^1P_1 \end{cases} \quad (2)$$

where k_0 is the energy of the emitted photon and $k_0 = m_a - m_b$ in the non relativistic limit. α is the

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fine structure constant. Q_a and Q_b are the charge of the quark and anti-quark in units of $|e|$, μ is the reduced mass and $\frac{E_b(k_0)}{m_a} = 1$ in non relativistic limit.

$$\langle R_b|r|R_a\rangle = \int_0^\infty r^3 R_b(r) R_a(r) dr \qquad (3)$$

is the radial overlap integral which has the dimension of length, with $R_{a,b}(r)$ being the normalized radial wave functions for the corresponding states.

Results and Discussion

The E1 transition rates of D and D_s meson states have been calculated using equation 2. The possible $E1$ decay modes are listed in table. Most of the predictions for $E1$ transitions are in good agreement with other theoretical models. However, there are some differences in the predictions due to differences in phase space arising from different mass predictions and also from the wave function effects. We find our results are compatible with the results of other theoretical models. The M1 transition rates of D and D_s meson states have been calculated using equation. Allowed M1 transitions correspond to the triplet-singlet transition between S-wave states and between P-state of the same n quantum number, while hindered M1 transitions are either triplet-singlet or singlet-triplet transitions between S-wave states of different quantum numbers. The possible $M1$ decay modes are listed in table.

Table 1 Electric dipole (E1) transitions widths of D mesons.

Initial	Final	k (MeV)	$\Gamma(KeV)$	[2]	[3]	[4]
$D(1^3P_2)$	$D(1^3S_1)$	458	17.45	17.00	51	61.2
$D_1^{'}(1P)$	$D(1^3S_1)$	441	14.23	13.77	30.87	39.9
$D_1^{'}(1P)$	$D(1^1S_0)$	588	31.25	30.20	21.71	16.1
$D_1(1P)$	$D(1^3S_1)$	411	12.54	1.24	10.25	8.6
$D_1(1P)$	$D(1^1S_0)$	558	13.2	2.82	39.59	66
$D(1^3P_0)$	$D(1^3S_1)$	319	8.65	7.23	17	30

Table 2 Magnetic dipole (M1) transitions widths of D mesons.

Initial→ Final	k (MeV)	Γ(KeV)	[2]	[4]	[3]
$D(1^3S_1) \to D(1^1S_0)$	147	0.345	0.339	10.8	1.8
$D(2^3S_1) \to D(2^1S_0)$	74	0.087	0.007		
$D(3^3S_1) \to D(3^1S_0)$	14	0.019	0.001		
$D(2^3S_1) \to D(1^1S_0)$	772	7.54		100	
$D(2^1S_0) \to B(1^3S_1)$	551	8.647			

Table 3 Electric dipole (E1) transitions widths of D mesons.

Initial	Final	k (MeV)	$\Gamma(KeV)$	[2]	[3]
$1^3P_2 \to 1^3S_1$	460	3.12	8.8	44.1	19
$1P_1^{'} \to 1^3S_1$	424	5.46	4.76	8.90	5.6
$1P_1^{'} \to 1^1S_0$	568	6.21	3.49	54.5	15
$1P_1 \to 1^1S_0$	493	3.18	4.9	12.8	6.2
$1P_1 \to 1^3S_1$	349	1.87	0.13	15.5	5.5
$1^3P_0 \to 1^3S_1$	209	0.024	1.0	4.92	1.9

Table 4 Magnetic dipole (M1) transitions widths of D mesons.

Initial→ Final	k (MeV)	Γ(KeV)	[2]	[4]
$1^3S_1 \to 1^1S_0$	144	0.124	1.91	0.2
$2^3S_1 \to 2^1S_0$	35	0.024		
$3^3S_1 \to 3^1S_0$	32	0.002		
$2^3S_1 \to 1^1S_0$	751	2.56		
$2^1S_0 \to 1^3S_1$	572	2.15		

For mesons with unequal quark and antiquark masses the gluon exchange current operator has a spin-flip component. It therefore also contributes to the M1 decay rates of the heavy-light mesons. Although this contribution is much smaller than that of the confining interaction, it is significant in the case of the M1 transitions between the ground state vector and pseudoscalar heavy-light mesons, because of the partial cancellation between the matrix elements of the single quark current operators and those of the exchange current associated with the confining interaction.

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