Radiative dipole transitions of the D meson

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Introduction

The radiative transitions are important tools to determine the properties of heavy-light mesons. Using the radiative transitions one can probe the internal charge structure of hadrons, hence they are useful for determining the quantum numbers and hadronic structures of heavy-light quark mesons. The radiative transition amplitude is determined by the matrix element of the EM current between the initial quarkonium state i and the final state f, i.e., $\langle f \mid j^{\mu}_{em} \mid i\rangle$. The leading order transition amplitudes are electric dipole ($E1$) transition and magnetic dipole ($M1$) transitions [1, 2].

Methodology

The E1 matrix elements are evaluated by using the variational radial wave functions of the initial M_i and the final M_f state meson masses and performing the angular integration given by[3]

$$\Gamma_{(E1)}\left(n^{2S+1}L_J \to n^{'2S^{'}+1}L^{'}_{J'}+\gamma\right) = \frac{4\alpha e_Q^2}{3}\frac{E_\gamma^3 E_f}{M_i} C_{fi}\delta_{SS'}\left|\langle f\left|r\right|i\rangle\right|^2 \quad (1)$$

where $E_\gamma = \frac{M_i^2-M_f^2}{M_f^2}$ is the photon energy, m_Q is the quark mass, e_Q is the quark charge in units of $|e|$ and E_f is the energy of final state. The C_{fi} is the angular momentum matrix element, given by

$$C_{fi} = \max\left(L, L^{'}\right)\left(2J^{'}+1\right)\left\{\begin{array}{ccc} L^{'} & J^{'} & S \\ J & L & 1\end{array}\right\}^2 \quad (2)$$

where{:::} is a 6-j symbol. The overlap integral is

$$\langle f\left|r\right|i\rangle = \int dr R_{n_i l_i}\left(r\right) R_{n_f l_f}\left(R\right). \quad (3)$$

The E1 radiative transition widths are listed in Table (I).

The M1 radiative transitions can be evaluated with the following expression [4]

$$\Gamma_{M1}\left(n^{2S+1}L_J \to n^{'2S^{'}+1}L^{'}_{J'}\right) = \frac{4\alpha e_Q^2}{3m_Q^2}\frac{E_\gamma^3 E_f}{M_i} S_{fi}\left|\mathcal{M}_{fi}\right|^2, \quad (4)$$

where, S_{fi}, is given by

$$S_{fi} = 6\left(2S+1\right)\left(2S^{'}+1\right)\left(2J^{'}+1\right) \times \left\{\begin{array}{ccc} J & 1 & J^{'} \\ S^{'} & L & S\end{array}\right\}^2 \left\{\begin{array}{ccc} 1 & 1/2 & 1/2 \\ 1/2 & S^{'} & S\end{array}\right\}^2 \quad (5)$$

here L = 0 for S-waves and

$$\mathcal{M}_{fi} = \int dr R_{n_i l_i}\left(r\right) j_0\left(E_\gamma r/2\right) R_{n_f l_f}\left(R\right); \quad (6)$$

$j_0(x)$ is the spherical Bessel function.

Rates for the allowed transitions between the spin-triplet and the spin-singlet states are given in Table (II). We employ Gaussian wave function for the calculation of the overlap integrals. The form of the wave function is given by

$$R_{nl}\left(r\right) = \mu^{\frac{3}{2}}\left(\frac{2\left(n-1\right)!}{\Gamma\left(n+l+1/2\right)}\right)^{\frac{1}{2}}\left(\mu r\right)^l \times e^{-\mu^2 r^2/2} L_{n-1}^{l+1/2}\left(\mu^2 r^2\right), \quad (7)$$

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TABLE I: Electric dipole (E1) transition widths of D mesons.

Meson transition		Masses(in GeV)		E_γ(MeV)	Present Work	Others (Γ in KeV)		
Initial	Final	M_i	M_f		Γ(KeV)	[5]	[6]	[7]
$D(1^3P_2)$	$D(1^3S_1)$	2.461	2.010	410	14.17	17.00	51	61.2
$D_1^{'}(1P)$	$D(1^3S_1)$	2.447	2.010	398	0.20	13.77	30.87	39.9
$D_1^{'}(1P)$	$D(1^1S_0)$	2.447	1.884	498	25.50	30.20	21.71	16.1
$D_1(1P)$	$D(1^3S_1)$	2.425	2.010	380	11.26	1.24	10.25	8.6
$D_1(1P)$	$D(1^1S_0)$	2.425	1.884	481	0.36	2.82	39.59	66
$D(1^3P_0)$	$D(1^3S_1)$	2.357	2.010	322	6.86	7.23	17	30
$D(2^3S_1)$	$D(1^3P_2)$	2.655	2.010	187	1.89	1.59		
$D(2^3S_1)$	$D(1^3P_0)$	2.655	2.357	281	1.29	1.52		
$D(2^1S_0)$	$D_1^{'}(1P)$	2.582	2.425	131	1.18	1.85		
$D(2^1S_0)$	$D_1(1P)$	2.582	2.425	152	0.03	2.69		

TABLE II: Magnetic dipole (M1) transitions widths of D mesons.

Meson transition	Masses(in GeV)		E_γ (MeV)	Present Work	Others (Γ in KeV)		
	M_i	M_f		Γ(KeV)	[5]	[7]	[6]
$D(1^3S_1) \to D(1^1S_0)$	2.010	1.884	123	0.271	0.339	10.8	1.8
$D(2^3S_1) \to D(2^1S_0)$	2.655	2.582	72	0.055	0.007		
$D(3^3S_1) \to D(3^1S_0)$	3,239	3.186	53	0.021	0.001		
$D(2^3S_1) \to D(1^1S_0)$	2.655	1.884	659	6.371		100	
$D(2^1S_0) \to B(1^3S_1)$	2.582	2.010	508	8.594			

here μ is the variational parameter, n, l are the quantum numbers of the bound state and L are the Laguerre polynomials. The variational parameter μ was fitted using virial theorem by using a relativized Hamiltonian. For details see ref [8]. The fitted values of μ are 0.390, 0.281, 0.233 and 0.309 GeV^{-1} for the 1S, 2S, 3S and 1P states. The masses are also taken from ref [8].

Discussion

In the present article we have evaluated E1 and M1 transition widths of the D mesons within a potential model scheme. It can be seen from tables (I) and (II) that the widths of E1 and M1 transitions obtained by various schemes are not in mutual agreement. Thus in the absence of reliable experimental measurements it is difficult to single out any particular model.

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