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Combination of Colour Favoured and Colour Suppressed on D Meson Decays

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Abstract

In this research we described the effective Hamiltonian theory and applied this theory to the calculation of current-current ($Q_{1,2}$) and QCD penguin ($Q_{3,\ldots,6}$) c quark decay rates. We calculated the decay rates of semileptonic and hadronic of charm quark in the effective Hamiltonian theory. We investigated the decay rates of D meson decays according to Spectator Quark Model (SQM) for the calculation of D meson decays. We obtained the total decay rates of semileptonic and hadronic of charm quark in the effective Hamiltonian according to colour Favoured (C-F) and colour Suppressed (C-S). We combined them and to added amplitude of processes colour Favoured and colour Suppressed (F+S) and obtained the decay rates of them.

Keywords: c quark; Hadronic; *D* meson; Colour favoured; Colour suppressed

Introduction: Effective Hamiltonian

As a weak decay under the presence of the strong interaction, D meson decays require special techniques. The main tool to calculate such D meson decays is the effective Hamiltonian theory. It is a two step program, starting with an operator product expansion (OPE) and performing a renormalization group equation (RGE) analysis afterwards. The necessary machinery has been developed over the past years. The derivation starts as follows: If the kinematics of the decay are of the kind that the masses of the internal particle M_i are much larger than the external momenta P, $M_i^2 >> p^2$, then the heavy particle can be integrated out. This concept takes concrete form with the functional integral formalism. It means that the heavy particles are removed, as dynamical degrees of freedom, from the theory. Hence their fields do not appear in the effective Lagrangian anymore. Their residual effect lies in the generated effective vertices. In this way an effective low energy theory can be constructed from a full theory like the Standard Model. A well known example is the four-Fermi interaction, where the W-boson propagator is made local for $M_W^2 >> q^2$ (q denotes the momentum transfer through the W):

$$-i\,(g_{\mu\nu})/(q^2 - M_W^2) \\ \rightarrow ig_{\mu\nu}\,[(1/M_W^2) + (q^2/M_W^4) + \ldots], \tag{1}$$

where the ellipsis denote terms of higher order in $1/M_W$.

Apart from the t quark the basic framework for weak decays quarks is the effective field theory relevant for scales $M_W, M_Z, M_t >> \mu$ [1]. This framework, as we have seen above, brings in local operators, which

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govern "effectively" the transition in question.

It is well known that the decay amplitude is the product of two different parts, whose phases are made of a weak (Cabbibo-Kobayashi-Maskawa) and a strong (final state interaction) contribution. The weak contributions to the phases change sign when going to the CP-conjugate process, while the strong ones do not. Indeed the simplest effective Hamiltonian without QCD effects ($c \to su\bar{s}$) is

$$H^0_{eff} = 2\sqrt{2}G_F\, V_{sc}V^*_{su}\, Q_1, \quad (2)$$

where G_F is the Fermi constant, V_{ij} are the relevant CKM factors and

$$Q_1 = (\bar{s}_\alpha c_\alpha)_{V-A}\,(\bar{u}_\beta s_\beta)_{V-A}, \quad (3)$$

is a $(V-A)$, $(V-A)$ is current-current local operator.

This simple tree amplitude introduces a new operator Q_2 and is modified by the QCD effect to

$$H_{eff} = 2\sqrt{2}G_F\, V_{sc}V^*_{su}\,(C_1Q_1 + C_2Q_2), \quad (4)$$

$$Q_2 = (\bar{s}_\beta c_\alpha)_{V-A}\,(\bar{u}_\alpha s_\beta)_{V-A}. \quad (5)$$

where C_1 and C_2 are Wilson coefficients. The situation in the Standard Model is, however, more complicated because of the presence of additional interactions in particular penguins which effectively generate new operators. These are in particular the gluon, photon and Z^0-boson exchanges and penguin c quark contributions as we have seen before.

Consequently the relevant effective Hamiltonian for D-meson decays involves generally several operators Q_i with various colour and Dirac structures which are different from Q_1. The operators can be grouped into three categories [2]: $i = 1, 2-$ current-current operators; $i = 3, ..., 6-$ gluonic penguin operators. Moreover each operator is multiplied by a calculable Wilson coefficient $C_i(\mu)$:

$$H_{eff} = 2\sqrt{2}G_F \sum_{i=1}^{6} d_i(\mu)Q_i(\mu), \quad (6)$$

where $d_i(\mu) = V_{CKM}C_i(\mu)$ and V_{CKM} denotes the relevant CKM factors that are:

$$d_{1,2} = V_{ic}V^*_{jk}C_{1,2}, \quad d_{3,...,6} = -V_{tc}V^*_{tk}C_{3,...,6} \quad (7)$$

The partial decay rate in the c rest frame is given by

$$d^2\Gamma_{Q_1,...,Q_6}/dp_i dp_k$$
$$= (G_F^2/\pi^3)\, p_i\, p_k\, E_{\bar{j}}\,\{\alpha_1(p_i.p_k/E_iE_k) \quad (8)$$
$$+\alpha_2(p_i.p_{\bar{j}}/E_iE_{\bar{j}}) + \alpha_3(m_k m_{\bar{j}}/E_kE_{\bar{j}})\}.$$

We should take the variable p_i and p_k, or x and y as,

$$p_i = xM_c/2, \qquad p_k = yM_c/2 \quad (9)$$

The partial decay rate in the c rest frame is given by

$$d^2\Gamma_{Q_1,...,Q_6}/dxdy$$
$$= \Gamma_{0c}\,(\alpha_1 I^1_{ps} + \alpha_2 I^2_{ps} + \alpha_3 I^3_{ps}). \quad (10)$$

Here

$$\alpha_1 = |d_1+d_2+d_3+d_4|^2 + 2|d_1+d_4|^2 + 2|d_2+d_3|^2,$$
$$\alpha_2 = |d_5+d_6|^2 + 2|d_5|^2 + 2|d_6|^2), \quad (11)$$
$$\alpha_3 = \mathrm{Re}\{(3d_1+d_2+d_3+3d_4)d^*_6$$
$$+(d_1+3d_2+3d_3+d_4)d^*_5\}.$$

and the phase space parameters are given by

$$I^1_{ps} = 6xy.f_{ab}.(1-h_{abc}),$$
$$I^2_{ps} = 6xy.f_{bc}.(1+h_{bca}), \quad (12)$$
$$I^3_{ps} = 6xy.f_{ac}.h_{xa}.h_{yc}.$$

where

$$h_{xa} = [1-(x^2/(x^2+a^2))]^{1/2},$$
$$h_{yc} = [1-(y^2/(y^2+c^2))]^{1/2},$$
$$h_{xb} = [1-(x^2/(x^2+b^2))]^{1/2},$$
$$h_{yb} = [1-(y^2/(y^2+b^2))]^{1/2},$$
$$\Gamma_{0c} = G_F^2 M_c^5/192\pi^3$$
$$f_{ab} = 2-\sqrt{x^2+a^2}-\sqrt{y^2+b^2}, \quad (13)$$
$$f_{bc} = 2-\sqrt{x^2+b^2}-\sqrt{y^2+c^2},$$
$$f_{ac} = 2-\sqrt{x^2+a^2}-\sqrt{y^2+c^2},$$
$$h_{abc} = \frac{(f_{ab})^2-(c^2+x^2+y^2)}{2\sqrt{x^2+a^2}\sqrt{y^2+b^2}},$$
$$h_{bca} = \frac{(f_{bc})^2-(a^2+x^2+y^2)}{2\sqrt{x^2+b^2}\sqrt{y^2+c^2}},$$
$$h_{acb} = \frac{(f_{ac})^2-(b^2+x^2+y^2)}{2\sqrt{x^2+a^2}\sqrt{y^2+c^2}}.$$

Spectator Model

In the spectator model [3-6] the spectator quark is given a non-zero momentum having in this work a Gaussian distribution, represented by a free (but adjustable) parameter, Λ :

$$P(|p_s|^2) = (1/\pi^{3/2}\Lambda^3)\ e^{-(p_s^2/\Lambda^2)}. \tag{14}$$

The total meson decay rate through a particular mode is then assumed to be

$$\Gamma_{total} = \int \frac{d^2\Gamma}{dp_i dp_k} P(|p_s|^2) d^3 p_s dp_i dp_k , \tag{15}$$

equal to the initiating decay rate. We have

$$\begin{aligned} \frac{d^2\Gamma}{dM_{is} dM_{k\bar{j}}} &= \frac{2\pi M_{is} M_{k\bar{j}}}{m_c} \\ &\times \int \frac{E_i p_s}{p_i^2} \frac{d^2\Gamma}{dp_i dp_k} P(|p_s|^2) dp_s dp_k . \end{aligned} \tag{16}$$

Here

$$\begin{aligned} M_{is}^2 &= (p_i + p_s).(p_i + p_s) \\ &= m_i^2 + m_s^2 + 2(E_i E_s - p_i p_s \cos\theta_{is}) \\ M_{k\bar{j}}^2 &= (p_k + p_{\bar{j}}).(p_k + p_{\bar{j}}) \\ &= m_k^2 + m_{\bar{j}}^2 + 2(E_k E_{\bar{j}} - p_k p_{\bar{j}} \cos\theta_{k\bar{j}}). \end{aligned} \tag{17}$$

The integration range is restricted by $|\cos\theta_{kj}| \le 1$. We call this mode of quark and antiquark combination ***process(C - F)*** (colour favoured). It is also possible that the spectator antiquark combines with the quark q_k , for which we get

$$\begin{aligned} \frac{d^2\Gamma}{dM_{ks} dM_{i\bar{j}}} &= \frac{2\pi M_{ks} M_{i\bar{j}}}{M_c} \\ &\times \int \frac{E_k p_s}{p_k^2} \frac{d^2\Gamma}{dp_i dp_k} P(|p_s|^2) dp_s dp_i . \end{aligned} \tag{18}$$

We call this ***process(C - S)*** (colour suppressed). Summing, the decay rates of B mesons for ***process(C - F)*** and ***process(C - S)*** are:

$$\begin{aligned} \Gamma_{(C-F)} &= \int_{m_{\min is}}^{m_{cutis}} \int_{m_{\min k\bar{j}}}^{m_{cutk\bar{j}}} \frac{d^2\Gamma}{dM_{is} dM_{k\bar{j}}} dM_{is} dM_{k\bar{j}} , \\ \Gamma_{(C-S)} &= \int_{m_{\min ks}}^{m_{cutks}} \int_{m_{\min i\bar{j}}}^{m_{cuti\bar{j}}} \frac{d^2\Gamma}{dM_{ks} dM_{i\bar{j}}} dM_{ks} dM_{i\bar{j}} . \end{aligned} \tag{19}$$

where $m_{\min is} = (m_{q_i} + m_{q_s})$, $m_{cutis} = M_{q_i q_s}$ and so on.

Effective Hamiltonian Spectator Model

The differential decay rates for two boson system in the spectator quark model for current-current plus penguin operators in the effective Hamiltonian is given by,

$$\begin{aligned} &\frac{d^2\Gamma_{Q_1,\ldots,Q_6}}{d(q_{si}/M_c)d(q_{k\bar{j}}/M_c)} = \\ &\Gamma_{0c} \frac{8q_{si}q_{k\bar{j}}}{\sqrt{\pi}M_c} \frac{\beta^2}{\Lambda} \frac{\sqrt{(2m_i/M_c)^2 + x^2}}{x^2} \\ &\times \int_0^1 dy \int_0^1 dz\, \zeta_{ps(q,z)}^{eff} z e^{-\beta^2 z^2} \end{aligned} \tag{20}$$

Where

$$\zeta_{ps(q,z)}^{eff} = \alpha_1\zeta_1^{eff} + \alpha_2\zeta_2^{eff} - \alpha_3\zeta_3^{eff} . \tag{21}$$

The integration region is restricted by the condition $\cos\theta_{is} \le 1$, thus

$$\begin{aligned} &\zeta_1^{eff}, \zeta_2^{eff}, \zeta_3^{eff} \\ &= \begin{cases} \zeta_{1ps}^{eff}, \zeta_{2ps}^{eff}, \zeta_{3ps}^{eff} & if \quad (f_{si(z)})^2 \le 1 \\ 0 & otherwise \end{cases} . \end{aligned} \tag{22}$$

Where

$$\begin{aligned} f_{si(z)} = \Big(&[(m_i + m_s)/M_c]^2 - (q_{si}/M_c)^2 \\ &+ (1/M_c)\sqrt{m_s^2 + (\beta\Lambda z)^2} \\ &\times\sqrt{(2m_i/M_c)^2 + x^2} \Big)/(\beta\Lambda xz/M_c). \end{aligned} \tag{23}$$

Therefore the phase space parameters will be defined by,

$$\begin{aligned} \zeta_{1ps}^{eff} &= 6xy.f_{ab}.(1-h_{abc}), \\ \zeta_{2ps}^{eff} &= 6xy.f_{bc}.(1+h_{bca}), \\ \zeta_{3ps}^{eff} &= 6xy.f_{ac}.h_{xa}.h_{yc} \end{aligned} \tag{24}$$

Now, we can integrate over the two mass cuts (two boson systems), and obtain the hadronic decay rates as follows,

$$\Gamma'_{Q_1,...,Q_6}$$
$$=\int_{\min}^{m_{cut}}\int_{\min'}^{m'_{cut}}\frac{d^2\Gamma_{Q_1,...,Q_6}}{d(q_{si}/M_c)d(q_{k\bar{j}}/M_c)}dm_{cut}\,dm'_{cut}\,,$$
$$=\Gamma_{0c}\int_{\min}^{m_{cut}}\int_{\min'}^{m'_{cut}}\frac{8q_{si}\,q_{k\bar{j}}}{\sqrt{\pi}M_c}\frac{\beta^2}{\Lambda}\frac{\sqrt{(2m_i/M_c)^2+x^2}}{x^2} \tag{25}$$
$$\times\int_0^1 dy\int_0^1 dz\ \ \zeta^{eff}_{ps(q,z)}\,ze^{-\beta^2z^2}dm_{cut}\,dm'_{cut}\,.$$

Decay Rates of Processes C-F plus C-S (F+S)

Now we want to calculate the decay rates of the effective Hamiltonian ($Q_1,...,Q_6$) for F+S at quark-level and spectator model. The effective Hamiltonian for F+S is given by

$$H^{A+B}_{eff}=H^{b\to ik\bar{j}}_{eff}+H^{b\to i\bar{j}k}_{eff}\,. \tag{26}$$

where $H^{c\to ik\bar{j}}_{eff}$ defined by Eq. (8) and we can obtain $H^{c\to i\bar{j}k}_{eff}$. The decay rates of current-current plus penguin for F+S is given by,

$$d^2\Gamma^{F+S}_{EH}/dxdy=\Gamma_{0c}\,(I_{1ps}+I_{2ps}+I_{3ps})\,, \tag{27}$$

The phase space parameters defined by

$$\begin{aligned}I_{1ps}&=6xy\,.f_{ab}\,.[\alpha_1((3/2)-h_{abc})\\&\quad+\alpha_2-\alpha_3h_{xa}h_{yb}\,],\\I_{2ps}&=-6xy\,.f_{ac}\,.[\alpha_1h_{acb}+\alpha_3h_{xa}h_{yc}\,],\\I_{3ps}&=6xy\,.f_{bc}\,.[(\alpha_1/2)h_{bca}\\&\quad+\alpha_2(h_{xb}h_{yc}-h_{bca})].\end{aligned} \tag{28}$$

Numerical Results

As an example of the use of the formalism above, we use the standard Particle Data Group [7] parameterization of the CKM matrix with the central values

$$\theta_{12}=0.221\,,\qquad\theta_{13}=0.0035\,,\qquad\theta_{23}=0.041\,,$$

and choose the CKM phase δ_{13} to be $\pi/2$. Following Ali and Greub [2] we treat internal quark masses in tree-level loops with the values (GeV) $m_b=4.88$, $m_s=0.2$, $m_d=0.01$, $m_u=0.005$, $m_c=1.5$, $m_e=0.0005$, $m_\mu=0.1$, $m_\tau=1.777$ and $m_{\nu_e}=m_{\nu_\mu}=m_{\nu_\tau}=0$.

Following G. Buccella [8], we choose the effective Wilson coefficients C^{eff}_i for the various $c\to q$ transitions.

a) The total decay rate and branching ratios hadronic modes according to the effective Hamiltonian theory (see Eq. (10)) show in Table 1. We see that mode $c\to su\bar{d}$ is dominant. The total c-quark decay rate of the Effective Hamiltonian is given by

$$\begin{aligned}\Gamma^{EH}_{total}\,(c\to anything)&=\Gamma(c\to s\ \ anything)\\&\quad+\Gamma(c\to d\ \ anything)\\&=9.261\times10^{-13}+0.606\times10^{-13}\,GeV\,,\\&=9.867\times10^{-13}\,GeV\,,\end{aligned}$$

b) Now we can obtain the mean lives of the charm quark (D meson) theoretically and compare with the experimental mean life of $D^{\pm},D^0$ and D^+_s, so

$$Mean\ \ life^{EH}_{theory}\,(D)=\hbar/\Gamma^{EH}_{total}=1.067\times10^{-12}\ Sec.$$

and

$$Mean\ \ life_{\exp}(D^+)=(1.040\pm0.007)\times10^{-12}\,Sec\,,$$
$$Mean\ \ life_{\exp}(D^0)=(0.410\pm0.001)\times10^{-12}\,Sec\,,$$
$$Mean\ \ life_{\exp}(D^+_s)=(0.461\pm0.015)\times10^{-12}\,Sec\,.$$

Also, we can compare the branching ratio of the semileptonic theoretically and experimentally, so

$$\begin{aligned}&BR\,(c\to e^+\ \ anything)_{theory}\\&=BR\,(c\to se^+\nu_e)+BR\,(c\to de^+\nu_e)\\&=147.96\times10^{-3}+8.702\times10^{-3}=15.67E-2\,,\end{aligned}$$

and

$$BR_{\exp}(D^+\to e^+\ \ anything)=(17.2\pm1.9)E-2\,,$$
$$BR_{\exp}(D^0\to e^+\ \ anything)=(6.87\pm0.8)E-2\,,$$
$$BR_{\exp}(D^+_s\to e^+\ \ anything)<20\times10^{-2}.$$

We see that the theoretical and experimental results are close.

c) We have used in the Spectator Quark Model the value $\Lambda=0.6$ GeV [9]. For the maximum mass of the quark-antiquark systems (m_{cut}) we take a value midway between the lowest mass 1^- state and the next most massive meson. Thus we take, for $(s\bar{u})$ or $(s\bar{d})$, $m_{cut\,(u\bar{d})}=0.877GeV$ between the $\rho(0.770)$ and the $a_0(0.984)$; for $(u\bar{u})$ and $(d\bar{d})$, $m_{cut\,(u\bar{u})}=m_{cut\,(d\bar{d})}=0.870GeV$ between $\omega(0.782)$ and $\eta'(0.958)$.

Table 1. Decay rates (Γ) and Branching Ratio (BR) of Effective Hamiltonian (EH) and F+S of Effective Hamiltonian of c quark

Process	$\Gamma_{EH}\ \times 10^{-15}$	$BR_{EH}\ \times 10^{-3}$	$\Gamma_{EH}^{F+S}\ \times 10^{-15}$	$BR_{EH}^{F+S}\ \times 10^{-3}$
$c \to du\bar{d}$	31.689	32.12	35.611	31.262
$c \to du\bar{s}$	1.0785	1.093	1.4608	1.2824
$c \to su\bar{d}$	409.44	414.95	554.45	486.74
$c \to su\bar{s}$	23.836	24.157	26.927	23.638

For example, we can calculate the Branching Ratios of mode $c \to du\bar{d}$ in the Tree-level and Effective Hamiltonian spectator model. The modes $c \to du\bar{d}$ is for decays $D^+ \to \pi^0\pi^+$, $D^+ \to \eta\ \pi^+$, $D^+ \to \rho^0\pi^+$, $D^+ \to \omega\ \pi^+$, $D^+ \to \pi^0\rho^+$, $D^+ \to \eta\ \rho^+$, $D^+ \to \rho^0\rho^+$ and $D^+ \to \omega\ \rho^+$. We told that, in this cases got a two-boson system and, therefore two masses of cut for bosons system. We choose masses of cut for two boson system $m_{cut\,1} = 0.870/M_c$ and $m_{cut\,2} = 0.877/M_c$. Theoretically, the Branching Ratio of Effective Hamiltonian spectator model is given by,

$$BR_{EH}\ (c \to du\bar{d})$$

$$= \Gamma_{EH}\ (c \to du\bar{d})_{cut\,1,cut\,2} / \Gamma_{total\ \ EH}\ (c \to anything)$$

$$= 1.2502 \times 10^{-14} / 9.867 \times 10^{-13}$$

$$= 1.2671 \times 10^{-2}$$

The masses of some mesons and the masses of cut are presented in Table 2. The results are presented in Table 3 and compared, where data is available, with the sum of the branching ratios into mesons with masses less than the above cutoff masses. Also all the experimental and theoretical D meson decays in spectator model classified and given by Table 3.

d) The decay rates of c quark for F+S shown in the Table 1 and the total decay rates of F+S is given by

$$(c \to du\bar{d}\ )\quad D^+ \to (\pi^0, \eta, \rho^0, \omega), (\pi^+, \rho^+)$$

$$BR_{EH}^{F+S} = 2.1023 \times 10^{-2},$$

$$(c \to su\bar{d}\ )\quad D^+ \to (\pi^+, \rho^+), (\bar{K}^0, \bar{K}^{*+})$$

$$BR_{EH}^{F+S} = 51.2871 \times 10^{-2},$$

$$(c \to su\bar{s}\ )\quad D^+ \to (\eta', \varphi), (K^+, K^{*+})$$

$$BR_{EH}^{F+S} = 3.8671 \times 10^{-2}.$$

The experimental of Branching Ratios of D meson hadronic decays show in Appendix A.

Table 2. The masses of some mesons and the masses of cut for D meson decay processes

System of Quark	Particle	Mass (GeV)	Cutoff Mass (GeV)
$s\bar{u}$, $s\bar{d}$	K	0.494	1.081
	K^*	0.892	
	K^{**}	1.270	
$u\bar{d}$	K	0.140	0.877
	K	0.770	
	a_0	0.984	
$u\bar{u}$, $d\bar{d}$	K	0.140	0.870
	η	0.547	
	ρ^0	0.770	
	ω	0.782	
	η'	0.958	
$s\bar{s}$	η'	0.958	1.150
	ϕ	1.020	
	ϕ	1.680	

Table 3. Experimental and theoretical of spectator model of Branching Ratios of hadronic for D meson decays

1- Decay of c Quark
2- Experimental of Branching Ratio, *process* ($C-F$)
3- Experimental of Branching Ratio, *process* ($C-S$)
4- Theoretical of Branching Ratio, *process* ($C-F$)
5- Theoretical of Branching Ratio, *process* ($C-S$)
6- Theoretical of Branching Ratio, *process* ($F+S$)

Processes of D^+	Processes of D^0	Processes of D_s^+
1- $c \to du\bar{d}$		
2- <(3.04±0.25)×10^{-2}	(1.25±0.11)×10^{-3}	(14.5±2.8)×10^{-3}
3- <(3.04±0.25)×10^{-2}	(8.4±2.2)×10^{-4}	<2.9×10^{-3}
4- 1.2671×10^{-2}	1.2834×10^{-2}	1.2723×10^{-2}
5- 1.2931×10^{-2}	1.2543×10^{-2}	1.2398×10^{-2}
6- 2.1023×10^{-2}	———	———
1- $c \to su\bar{s}$		
2- (6.74±2.62)×10^{-2}	(9.63±2.07)×10^{-3}	<5.0×10^{-4}
3- (4.51±0.1)×10^{-2}	(7.37±0.29)×10^{-3}	<5.0×10^{-4}
4-1.9543×10^{-2}	1.9378×10^{-2}	1.9859×10^{-2}
5-1.9213×10^{-2}	1.8975×10^{-2}	1.9453×10^{-2}
6- ———	———	3.8671×10^{-2}

Conclusions

We used the effective Hamiltonian theory and spectator quark model for c quark and calculated hadronic decays of D mesons. In this model we added decays of channel hadronic decays of D mesons. For colour favoured and suppressed we consider the channel $c \to du\bar{d}$ (*e.g.* $D^+ \to \pi^0\pi^+$) and achieved theoretical values very close to experimental ones. Finally the case in which the theoretical values are better than the amplitude of all the calculated decay rates was shown. We obtain the total decay rates of hadronic of charm quark in the effective Hamiltonian according to colour Favoured and colour Suppressed, and then to added amplitude of processes colour Favoured and colour Suppressed and obtain the decay rates of them. Using the Spectator Model, we obtain the Branching Ratio of some D meson decays.

According to Table 1, we can to compare the decay rates of processes $c \to du\bar{d}$, $c \to du\bar{s}$ and $c \to su\bar{d}$, $c \to su\bar{s}$. The channels of $c \to du\bar{s}$ and $c \to su\bar{d}$ have Tree-Level decay rates and the channels of $c \to du\bar{d}$ and $c \to su\bar{s}$ have Tree-Level plus Penguin decay rates. According to Table 1, we see that the decay rates of channels $c \to du\bar{d}$ and $c \to su\bar{s}$ of colour favoured plus colour suppressed more than the decay rates of the effective Hamiltonian, hence the branching ratio of colour favoured plus colour suppressed less than the effective Hamiltonian. When we put the values of channels $c \to du\bar{d}$ and $c \to su\bar{s}$ into the theoretical model, we see that the theoretical and experimental values are close.

In Table 3, we see that the Effective Hamiltonian branching ratio of colour favoured plus colour suppressed is better than the effective Hamiltonian branching ratio of colour favoured or colour suppressed. The experimental value of branching ratio of channel $c \to su\bar{s}$ (*e.g.* $D_s^+ \to \eta' K^+$, $D_s^+ \to \varphi K^{*+}$) is less than 5.0×10^{-4} and the theoretical value of branching ratio of colour favoured plus colour suppressed is less than 3.8671×10^{-2}. We see that the experimental and theoretical values are close. Also for channel $c \to du\bar{d}$ (*e.g.* $D^+ \to \pi^0\rho^+$, $D^+ \to \rho^0\pi^+$, $D^+ \to \omega\rho^+$, $D^+ \to \eta\pi^+$), The experimental value of branching ratio is less than $(3.04 \pm 0.25) \times 10^{-2}$ and the theoretical value of branching ratio of colour favoured plus colour suppressed is less than 2.1023×10^{-2}. We see that the experimental and theoretical value is closed.

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Appendix A. Experimental of Hadronic D Meson Decays

The experimental values of hadronic D meson decays according to [7] are given by,

1- Decay of c Quark
2- Decay of D Meson, *process* ($C-F$)
3- Decay of D Meson, *process* ($C-S$)
4- Experimental Branching Ratio, *process* ($C-F$)
5- Total Experimental Branching Ratio, *process* ($C-F$)
6- Experimental Branching Ratio, *process* ($C-S$)
7- Total Experimental Branching Ratio, *process* ($C-S$)

1- $c \to du\bar{d}$

2- $D^+ \to (\pi^0, \eta, \rho^0, \omega), (\pi^+, \rho^+)$, $D^0 \to (\pi^-, \rho^-), (\pi^+, \rho^+)$, $D_s^+ \to (K^0, K^{*0}), (\pi^+, \rho^+)$

3- $D^+ \to (\pi^0, \eta, \rho^0, \omega), (\pi^+, \rho^+)$,	$D^0 \to (\pi^0, \eta, \rho^0, \omega), (\pi^0, \eta, \rho^0, \omega)$,	$D_s^+ \to (\pi^0, \eta, \rho^0, \omega), (K^+, K^{*+})$
4- $\pi^0\pi^+, (2.5 \pm 0.7) \times 10^{-3}$ $\rho^0\pi^+, < 1.4 \times 10^{-3}$ $\eta\pi^+, (7.5 \pm 2.5) \times 10^{-3}$ $\omega\pi^+, < 7.0 \times 10^{-3}$ $\eta\rho^+, 1.2 \times 10^{-2}$	$\pi^-\pi^+, (1.25 \pm 0.11) \times 10^{-3}$	$K^0\pi^+, < 8.0 \times 10^{-3}$ $K^*(892)^0\pi^+, (6.5 \pm 2.8) \times 10^{-3}$
5- $< (3.04 \pm 0.25) \times 10^{-2}$	$(1.25 \pm 0.11) \times 10^{-3}$	$(14.5 \pm 2.8) \times 10^{-3}$
6- $\pi^0\pi^+, (2.5 \pm 0.7) \times 10^{-3}$ $\rho^0\pi^+, < 1.4 \times 10^{-3}$ $\eta\pi^+, (7.5 \pm 2.5) \times 10^{-3}$ $\omega\pi^+, < 7.0 \times 10^{-3}$ $\eta\rho^+, 1.2 \times 10^{-2}$	$\pi^0\pi^0, (8.4 \pm 2.2) \times 10^{-4}$	$K^+\rho^0, < 2.9 \times 10^{-3}$
7- $< (3.04 \pm 0.25) \times 10^{-2}$	$(8.4 \pm 2.2) \times 10^{-4}$	$< 2.9 \times 10^{-3}$
1- $c \to su\bar{s}$		
2- $D^+ \to (\bar{K}^0, \bar{K}^{*0}), (\pi^+, \rho^+)$,	$D^0 \to (K^-, K^{*-}), (K^+, K^{*+})$,	$D_s^+ \to (\eta', \varphi), (K^+, K^{*+})$
3- $D^+ \to (\eta', \varphi), (\pi^+, \rho^+)$,	$D^0 \to (\eta', \varphi), (\pi^0, \eta, \rho^0, \omega)$,	$D_s^+ \to (\eta', \varphi), (K^+, K^{*+})$
4- $\bar{K}^0K^+, (7.2 \pm 1.2) \times 10^{-3}$ $\bar{K}^*(892)^0K^+, (4.2 \pm 0.5) \times 10^{-3}$ $\bar{K}^0K^*(892)^+, (3.0 \pm 1.4) \times 10^{-2}$ $\bar{K}^*(892)^0K^*(892)^+, (2.6 \pm 1.1) \times 10^{-2}$	$K^+K^-, (4.33 \pm 0.27) \times 10^{-3}$ $K^*(892)^+K^-, (3.5 \pm 0.8) \times 10^{-3}$ $K^+K^*(892)^-, (1.8 \pm 1.0) \times 10^{-3}$	$\varphi K^+, < 5.0 \times 10^{-4}$
5- $(6.74 \pm 2.62) \times 10^{-2}$	$(9.63 \pm 2.07) \times 10^{-3}$	$< 5.0 \times 10^{-4}$
6- $\eta'(958)\pi^+, < 9.0 \times 10^{-3}$ $\eta'(958)\rho^+, < 1.5 \times 10^{-2}$ $\varphi\pi^+, (6.1 \pm 0.6) \times 10^{-3}$ $\varphi\rho^+, < 1.5 \times 10^{-2}$	$\varphi\pi^0, < 1.4 \times 10^{-3}$ $\varphi\eta, < 2.8 \times 10^{-3}$ $\varphi\omega, < 2.1 \times 10^{-3}$ $\varphi\rho^0, (1.07 \pm 0.29) \times 10^{-3}$	$\varphi K^+, < 5.0 \times 10^{-4}$
7- $(4.51 \pm 0.1) \times 10^{-2}$	$(7.37 \pm 0.29) \times 10^{-3}$ $< 5.0 \times 10^{-4}$	