

Semi-leptonic D_s^+ (1968) Decays as a Scalar



M. Naeem Shahid



(in collaboration with Amir Fariborz, Renata Jora and Joseph Schechter)

Department of Physics, Syracuse University, Syracuse, NY mnshahid@phy.syr.edu

The unusual multiplet structures associated with the light spin zero mesons have recently attracted a good deal of theoretical attention. Here we discuss some aspects associated with the possibility of getting new experimental information on this topic from semi-leptonic decays of heavy charged mesons into an isosinglet scalar or pseudoscalar plus leptons.

Motivation

On the experimental side of the subject, information on the light scalars has often been extracted from study of pion pion and other scattering processes. Another way is to search for scalar resonances explicitly in particle decay processes. Recently, the CLEO collaboration has reported [1] good evidence for the scalar $f_0(980)$ in the semi-leptonic decay of the $D_{s}^{+}(1968)$ meson. Since there seems to be more phase space available,



Three flavors are special 🐥

There is no problem finding a chiral formulation for a $q\bar{q}$ 16plet, M_a^b . However we can not find a suitable schematic meson wave function with the same chiral transformation property constructed, for example, as a "molecule" out of two such states. The closest we can come for a two-part "molecule" is:



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it may be possible to find other scalar iso-singlet states in this and similar semi-leptonic decays of heavy mesons. There are also isosinglet pseudoscalar states like the η and $\eta'(980)$ which can be studied and in fact have been already reported in the decays of the D_s^+ (1968).

Chiral SU(3) model

Schematically a chiral nonet is,

 $M_a^{\dot{b}} = (q_{bA})^{\dagger} \gamma_4 \left(\frac{1+\gamma_5}{2}\right) q_{aA}.$

The decomposition in terms of scalar and pseudoscalar fields ÍS,

 $M = S + i\phi$.

The Noether vector and axial currents reads:

 $V^{b}_{\mu a} = i \phi^{c}_{a} \stackrel{\leftrightarrow}{\partial_{\mu}} \phi^{b}_{c} + i \tilde{S}^{c}_{a} \stackrel{\leftrightarrow}{\partial_{\mu}} \tilde{S}^{b}_{c} + i (\alpha_{a} - \alpha_{b}) \partial_{\mu} \tilde{S}^{b}_{a},$ $A^{b}_{\mu a} = \tilde{S}^{c}_{a} \stackrel{\leftrightarrow}{\partial_{\mu}} \phi^{b}_{c} - \phi^{c}_{a} \stackrel{\leftrightarrow}{\partial_{\mu}} \tilde{S}^{b}_{c} + (\alpha_{a} + \alpha_{b}) \partial_{\mu} \tilde{S}^{b}_{a},$

where the normalization is $\alpha_1 + \alpha_2 = F_{\pi} \approx 130.4$ MeV and $\alpha_1 + \alpha_3 = F_K \approx 156.1$ MeV.

(a) (b)

 $\langle \pi^0(p) | V_{\mu 1}^3 | K^+(k) \rangle \sim f_+(t) (k+p)_{\mu} + f_-(t) (k-p)_{\mu},$

where the first term corresponds to Fig. (a) and second term to Fig. (b) and,

> $f_+ = -\frac{1}{\sqrt{2}},$ $f_{-} = -\frac{1}{\sqrt{2}} \left[\frac{\alpha_3 - \alpha_1}{\alpha_3 + \alpha_1} \right] \left[\frac{m_{\kappa}^2 - m_{\pi}^2}{m_{\kappa}^2 - t} \right].$

This decay allows one to learn something about the properties of the kappa meson. For this purpose it is necessary to use the process where a final μ^+ is observed rather than a final e^+ . That is because the contribution of the leptonic factor to $f_{-}(t)$ is proportional to the final lepton mass.

Different semi-leptonic decays of $D_{\rm c}^+$ (1968) P; (q) or F; (q) $D_{s}^{+}(p)$

$$M_{ag}^{\dot{b}\dot{h}} = \varepsilon_{agcd} \varepsilon^{\dot{b}\dot{h}\dot{e}\dot{f}} \left(M^{\dagger}\right)_{\dot{e}}^{c} \left(M^{\dagger}\right)_{\dot{f}}^{d}$$

However, instead of transforming under $SU(4)_L \times SU(4)_R$ as $(L,R) = (4,\overline{4})$ as desired, this object transforms as (L,R) = 1 $(6,\overline{6})$, owing to the two sets of antisymmetric indices (ag and $b\dot{h}$) which appear. Hence, it should not mix in the chiral symmetry limit with the initial four flavor $q\bar{q}$ state. It would be possible to multiply the right hand side by a third field $(M^{\dagger})_{i}^{s}$. This does give the correct transformation property to mix with the four flavor part. However it corresponds to a three quarkthree antiquark molecule. We assume that, especially after quark mass terms are added, an "elementary particle" state of such a form is unlikely to be bound.

Results

• Theoretical predictions

The results depends on a range of $m [\pi (1300)] = 1300 \pm 100$ MeV and the light "quark mass ratio" A3/A1, which is varied over an appropriate range. For typical value of $m[\pi(1300)] =$ 1.215 GeV and with A3/A1 = 30 the predictions are:

	m_i (MeV)	Γ_i (MeV)	m_i (Me	$(\mathbf{V}) \Gamma_i (\mathrm{MeV})$					
	553	4.14×10^{-11}	477	4.56×10^{-12}					
	982	7.16×10^{-12}	1037	7 7.80 \times 10 ⁻¹³					
	1225	2.57×10^{-12}	1127	7 3.62 \times 10 ⁻¹⁴					
	1794	2.65×10^{-17}	1735	5 3.85 \times 10 ⁻¹⁴					
	psei	udoscalars		scalars					
• Experimentally three decay widths are known: $\begin{split} & \Gamma(D_s \to \eta e^+ \mathbf{v}_e) = (3.5 \pm 0.6) \times 10^{-11} \text{ MeV}, \\ & \Gamma(D_s \to \eta' e^+ \mathbf{v}_e) = (1.29 \pm 0.30) \times 10^{-11} \text{ MeV}, \\ & \Gamma(D_s \to f_0 e^+ \mathbf{v}_e) = (2.6 \pm 0.4) \times 10^{-12} \text{ MeV}. \end{split}$ • Over the range of $m[\pi(1300)]$ and $A_3/A_1 = 20$ an $A_3/A_1 = 30.$									
	η,		η_2	f_2					
7e-1	1		$A_3/A_1 = 20$ $A_1/A_2 = 20$ $A_1/A_3 = 20$	$2 \boxed{A_2 / A_1 = 20}$					
6e-1		$e_{A_1=20}$ 2e-11	$ \begin{array}{c} \bullet & A_3 / A_1 = 50 \\ \hline & & \text{Exp. upper bound} \\ \hline & & - & \text{Exp. lower bound} \end{array} $	$2 \begin{bmatrix} \mathbf{A}_{3} & \mathbf{A}_{1} &= 30 \\ \mathbf{E}_{2} & \mathbf{E}_{2} & \mathbf{E}_{2} & \mathbf{E}_{2} \\ \mathbf{E}_{3} & \mathbf{E}_{3} & \mathbf{E}_{3} & \mathbf{E}_{3} \\ \mathbf{E}_{3} & \mathbf{E}_{3} & \mathbf{E}_{3$					
5e-1	1 - Exp	$A_1 = 30$ p. upper bound p. lower bound 1.5e-11		2					
4e-1	- 1 <mark>- • • • •</mark>	■ 1e-11							
3e-1	-	1 5-	1						
50 1	1	5e-12	- 1e-12						

$n_i (MeV)$	$\Gamma_i ({ m MeV})$		$m_i ({\rm MeV})$	Γ_i (MeV)						
553	4.14×10^{-11}		477	4.56×10^{-12}						
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• •	• 2e-11	■ A — Ex Ex	$a_{A}^{5}/A_{1}^{1} = 30$ sp. upper bound sp. lower bound $4e-12 - 4e-12$	$A_3 / A_1 = 20$ $A_3 / A_1 = 30$ Exp. upper bound $-$						
$ \begin{array}{c} \bullet A_3, \\ \blacksquare A_3, \\ \hline Exp \\ - Ex$	$A_1 = 20$ $A_1 = 30$ b. upper bound b. lower bound 1.5e-11		 ■ 3e-12	Exp. lower bound						
	■ 1e-11			• 						
	J Se-12	•	• • 1e-12	■						
	$0 \bullet 125$	1.3	135 14 0							

SU(3) M-M' model

Another chiral field constructed out of two quarks and two anti-quarks [2],

where the meaning [3] of the superscript on the trace symbol is that the first term should be summed over the heavy quark index as well as the three light indices. This stands in contrast to the second term which is just summed over the three light quark indices pertaining to the two quark - two antiquark field M'. Since the Noether currents are sensitive only to this kinetic term in the model, the vector and axial vector currents with flavor indices 1 through 3 in this model are just the same as above. However if either or both flavor indices take on the value 4 (referring to the heavy flavor) the current will only have contributions from the field M. For example,



$$V^{a}_{\mu4}(total) = V^{a}_{\mu4} = i\phi^{c}_{4} \stackrel{\leftrightarrow}{\partial}_{\mu} \phi^{a}_{c} + iS^{c}_{4} \stackrel{\leftrightarrow}{\partial}_{\mu} S^{a}_{c},$$

$$A^{b}_{\mu a}(total) = A^{a}_{\mu 4} = S^{c}_{4} \stackrel{\leftrightarrow}{\partial}_{\mu} \phi^{a}_{c} - \phi^{c}_{4} \stackrel{\leftrightarrow}{\partial}_{\mu} S^{a}_{c}.$$

$$f_1, \eta_1 \sim n\bar{n},$$

$$f_2, \eta_2 \sim s\bar{s},$$

$$f_3, \eta_3 \sim ns\bar{n}\bar{s},$$

$$f_4, \eta_4 \sim nn\bar{n}\bar{n},$$

where s stands for a strange quark while n stands for a nonstrange quark. The unitegrated partial decay widths are,



Conclusions

1. It is encouraging that a very simple treatment of hadronic weak currents, involving product of two fields with no normalization constant, give reasonable results.

2. This can be applied to many other D and B semi-leptonic decays.

3. Further work will be to modify the currents by including vector and axial vector fields.

References

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