$\Sigma_c \bar{D}$ AND $\Lambda_c \bar{D}$ STATES IN A CHIRAL QUARK MODEL*

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Published 14 January 2014

We report our recent work on a dynamical investigation of the $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ states in a chiral quark model. Our results show that the $\Sigma_c - \bar{D}$ interaction is attractive, which consequently results in a $\Sigma_c \bar{D}$ bound state with the binding energy of about 5–42 MeV, unlike the case of $\Lambda_c \bar{D}$ state, which has a repulsive interaction and thus is unbound.

Keywords: $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ states; quark model; nucleon resonances.

PACS numbers: 13.75.Jz, 12.39.-x, 14.20.Gk

1. Introduction

One of the most important topics in hadron physics is to understand the structure and dynamical origin of baryon resonances. On quark level, baryon resonances

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are described as excited states of three constituent quarks (qqq) which are confined by a phenomenological confinement potential and interact through a residual interaction inspired by one gluon exchange (OGE)^{1,2} or through Goldstone boson exchanges (GBE).^{3,4} In chiral constituent quark models, it is found that some nucleon resonances are able to be accommodated as baryon-meson dynamically generated resonances.⁵⁻⁷ On hadron level, different approaches have also proposed different scenarios. In the K-matrix approximation approach and the unitary isobar model, all resonances are treated as genuine resonances.⁸⁻¹¹ In the chiral unitary approach, a completely different picture is delivered and resonances appear as dynamical effects through the re-scattering.¹²⁻¹⁴ In the dynamical coupled-channel hadron-exchange models, the Roper appears as dynamically generated resonance in the Jülich model,¹⁵ while it appears as genuine resonance in the EBAC model.¹⁶

Since different models give us different descriptions for resonances' structures, it is still confusing to us whether the baryon resonances should be described by 3-quark configurations (qqq) or 5-quark configurations ($qqqq\bar{q}$) or baryon-meson dynamically generated states or a mixture of them. The study of $\Sigma_c\bar{D}$ and $\Lambda_c\bar{D}$ states is of particular interest. If there exists a $\Sigma_c\bar{D}$ bound state or a $\Sigma_c\bar{D}$ - $\Lambda_c\bar{D}$ dynamically generated state, it will have more than 3.3 GeV excitation energy and thus will definitely exclude the explanation as three light quark configuration (qqq), and only the description that this state is dominated by hidden charm five constituent quark configuration ($qqqc\bar{c}$) or $\Sigma_c\bar{D}$ bound state or $\Sigma_c\bar{D}$ - $\Lambda_c\bar{D}$ resonance state or a mixture of them will be possible.

We report here our recent study of the $\Sigma_c\bar{D}$ and $\Lambda_c\bar{D}$ states in a chiral quark model.¹⁷ The quark configuration of the considered system is $(qqc)-(q\bar{c})$ with q being the light-flavor quark u or d . The interactions among various quark pairs considered in our work are

$$V_{ij} = \begin{cases} V_{ij}^{\text{OGE}} + V_{ij}^{\text{conf}} + \sum_{\text{M}} V_{ij}^{\text{M}}, & (ij = qq) \\ V_{ij}^{\text{OGE}} + V_{ij}^{\text{conf}}, & (ij = qQ, q\bar{Q}, Q\bar{Q}) \end{cases} \quad (1)$$

Where the interaction between the light-flavor quark pair qq are taken from our previous works.^{18,19} The light-heavy quark pair qc or $q\bar{c}$ and the heavy-heavy quark pair $c\bar{c}$ are considered to be interacted via OGE and confinement potential. Most of the parameters are taken from our previous works, and the new parameters are those associated with charm quark. The only one adjustable parameter is the charm quark mass m_c . Here we take three typical values to test the dependence of our results on m_c . The coupling constants of OGE and confinement strengths for light quark and heavy quark pair and for heavy quark pair are fixed by a fitting to the masses and stability conditions of the charmed baryons Σ_c , Λ_c and charmed mesons D , D^* and the charmonium J/ψ , η_c . The values of those parameters are listed in Table 1. See our original paper, Ref. 17, for more details of the formalism and parameters.

Table 1. Parameters associated with charm quark.

	m_c (GeV)	g_c	a_{uu}^c (fm ⁻²)	a_{uc}^c (fm ⁻²)	a_{cc}^c (fm ⁻²)	a_{uu}^{c0} (fm ⁻¹)	a_{uc}^{c0} (fm ⁻¹)	a_{cc}^{c0} (fm ⁻¹)
I	1.43	0.35	0.44	1.07	1.74	-0.38	-0.74	-0.73
	1.55	0.37	0.44	1.08	1.77	-0.38	-0.85	-0.93
	1.87	0.43	0.44	1.10	1.81	-0.38	-1.14	-1.44
II	1.43	0.77	0.41	1.70	1.83	-0.53	-1.15	-0.34
	1.55	0.82	0.41	1.72	1.68	-0.53	-1.27	-0.40
	1.87	0.94	0.41	1.76	1.04	-0.53	-1.57	-0.47
III	1.43	0.57	0.37	1.68	2.19	-0.46	-1.14	-0.71
	1.55	0.60	0.37	1.69	2.16	-0.46	-1.25	-0.85
	1.87	0.69	0.37	1.74	1.94	-0.46	-1.55	-1.17

2. Results and Discussion

We have performed a dynamical investigation of the $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ states with isospin $I = 1/2$ and spin $S = 1/2$ in our chiral quark models. We found that the interaction of Σ_c and $\bar{D}$ are attractive in the medium range for all those three values of charm quark mass $m_c = 1.43$ GeV, 1.55 GeV and 1.87 GeV and all those three models I, II and III (see Ref. 17 for details). Our further analysis demonstrated that in model I the attraction between Σ_c and $\bar{D}$ is dominated by σ exchange and the color magnetic force of OGE. In models II and III, the OGE among light-flavor quarks are largely reduced by vector-meson exchanges and the $\Sigma_c \bar{D}$ attraction is found to be dominated by σ and ρ exchanges.

Inspired by the moderately large $\Sigma_c \bar{D}$ attraction, we have solved the RGM equation for a bound state problem. The obtained $\Sigma_c \bar{D}$ binding energies are listed in Table 2, where the first and second columns denote the model and the charm quark mass, respectively, and the third column shows the corresponding binding energy for each set of parameters. One sees that the $\Sigma_c \bar{D}$ is really bound independent of the types of the models and the values of the charm quark mass we use. The binding energy is around 9 – 42 MeV in various models, which corresponding to an energy of 4.279 – 4.312 GeV for the $\Sigma_c \bar{D}$ bound state (the $\Sigma_c \bar{D}$ threshold is 4.321 GeV).

Table 2. The binding energy of $\Sigma_c \bar{D}$ (in MeV).

	m_c (GeV)	r confinement	r^2 confinement
I	1.43	9.3	4.5
	1.55	10.9	6.4
	1.87	15.3	11.0
II	1.43	28.3	9.3
	1.55	31.8	10.3
	1.87	41.6	10.0
III	1.43	19.7	7.3
	1.55	22.2	8.9
	1.87	28.6	11.3

We have also studied the $\Lambda_c \bar{D}$ system and found that the $\Lambda_c \bar{D}$ system is strongly repulsive for all those three models and all those three values of charm quark mass. No $\Lambda_c \bar{D}$ bound state was found as a matter of course due to this repulsion.

Further we have performed a $\Sigma_c \bar{D}$ - $\Lambda_c \bar{D}$ coupled-channels calculation and no $\Sigma_c \bar{D}$ - $\Lambda_c \bar{D}$ resonance state has been found. This is because the gap of the $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ thresholds, 166 MeV, is comparatively big and the transition matrix elements between $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ are too weak.

In Ref. 20, the $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ states have been studied in a coupled-channel unitary approach. There, a $\Sigma_c \bar{D}$ bound state is also found with the energy of about 4.240 – 4.291 GeV, and this state does not couple to $\Lambda_c \bar{D}$ channel. Although the binding energy given by Ref. 20 is bigger than that from our work, it makes sense that the results from different theoretical approaches are qualitatively similar. Note that the $\Sigma_c \bar{D}$ bound state, if it exists, cannot be accommodated in three light flavor quark configuration (qqq). Whether it can be explained as hidden charm five constituent quark configuration ($qqqc\bar{c}$) or not needs further detailed scrutiny.

3. Summary

We have performed a dynamical coupled-channel study of $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ states in a chiral quark model. Our results show that the $\Sigma_c \bar{D}$ interaction is attractive and a $\Sigma_c \bar{D}$ bound state can be formed as a consequence with the energy of about 4.279 – 4.316 GeV, while the $\Lambda_c \bar{D}$ is repulsive and unbound. The channel-coupling effects between $\Sigma_c \bar{D}$ and $\Lambda_c \bar{D}$ is negligible. Further investigations from other approaches and experiments are needed to confirm the existence of this $\Sigma_c \bar{D}$ bound state and to pin down its structure and mass.

Acknowledgments

This work was supported in part by the Fundamental Research Funds for the Central Universities of China, National Natural Science Foundation of China grant Nos. 10875133 and 10821063, Ministry of Science and Technology of China (2009 CB 825200), and China Postdoctoral Science Foundation (No. 20100480468). F.H. is grateful to the support by COSY FFE grant No. 41788390 (COSY-058).

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