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Nuclear Physics A 914 (2013) 447–453
NUCLEAR PHYSICS A
www.elsevier.com/locate/nuclphysa

Molecular bound states of charmed hadrons

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Received 28 December 2012; received in revised form 17 January 2013; accepted 18 January 2013

Abstract

Hadronic interactions between heavy-quark hadrons are studied. Focus is on the properties of the heavy quark interactions, and possible bound states of charmed baryon. The charmed deuteron states are studied in the meson exchange picture based on the chiral and heavy quark effective theory.

Keywords: Heavy quark; Heavy hadron; Charmed deuteron

1. Introduction

Strangeness Nuclear Physics has a long and successful history of excellent performance with close collaborations of theory and experiment. In the course of development, production, spectroscopy and decay of hyperons and hypernuclei have been studied intensively, and a new field of nuclear physics has been established. Our knowledge has been largely expanded towards the strong, electro-magnetic and weak interactions of strange mesons and baryons. One important achievement is to clarify the properties of the generalized nuclear force, *i.e.* the interactions between hyperons.

Recent developments in technology both in theory and experiments allow us to go forward and provide us with opportunities of exploring charm- and bottom-quark hadrons and their interactions.[1] Many of the newly-found quarkonium-like meson resonances, such as $X(3872)$, $Z(4430)$,

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[1] We do not consider the top quark, because it has a large decay width ($t \to bW$, etc.), about 2 GeV, so that the “top hadrons” are subject to not only QCD but also weak interactions.

http://dx.doi.org/10.1016/j.nuclphysa.2013.01.024

$Z_b(10610)$ and $Z_b(10650)$, etc., seem to be "exotic" so that they are not simply $\bar{q}q$ states. It has been conjectured that those are either tetra-quarks ($q^2\bar{q}^2$) or molecular bound states of two heavy hadrons. These narrow states are novel in hadron physics because no corresponding states are found in the light hadrons.

Charmed hadrons will be produced by the flavor transfer processes, (D, π), (D, N), etc., where a heavy quark is transfered from the initial hadron to the target. The other process is pair creation in hadronic reactions, $(\pi, D^{(*)})$, $(\bar{p}, D^{(*)})$, etc., where the elementary process is $g \to c\bar{c}$ creation. Another possible pair creation process is by leptons via $\to (e^+e^-, D^{(*)})$, etc., where $c\bar{c}$ is created from a virtual photon. Experimental facilities, such as J-PARC, PANDA, BELLE, and BES will be able to explore the charmed hadron physics by some of the above production channels. High energy heavy ion collisions, RHIC and LHCb, may also give us chances to study heavy-quark hadron spectroscopy.

In the heavy-quark hadron spectroscopy, we have various interesting subjects. One important study is of the excited states of HQ baryons, Qqq, where the light quarks can be regarded as a diquark cluster. Namely, the diquark is treated separately from the heavy quark, mainly because the magnetic (spin-dependent) interactions of the heavy quark is suppressed. For instance, the P-wave (negative-parity) excited states are classified into the two categories, one in which the diquark orbital motion is excited, and the other in which the diquark itself is excited to a negative parity diquark.

This picture is the result of heavy quark spin symmetry and the strong light-diquark correlations. If we consider the doubly heavy baryons, QQq states, then the spectroscopy probes the single light-quark spectrum, which becomes independent from the QQ dynamics.

Another interesting subject is a possible double-charm exotic meson: T_{cc} ($\bar{c}\bar{c}ud$, 1^+, $I = 0$), predicted at around 70 MeV below DD^* threshold due to the color-spin interaction between quarks. Recently, its excited state made of color-6 diquaks is also studied [1]. Because of the suppression of color-magnetic interaction the color-6 diquark state does not mix strongly with the ground state.

Thus, the charm and bottom quark physics is becoming one of the important subfields of hadron physics. In this report, we first discuss general properties of the heavy quark physics and the heavy quark effective theory, and then further apply the effective theory to hadronic molecular states, in particular the charmed deuteron system.

2. HQ dynamics

Heaviness of heavy quarks, c, and b, make them distinguished from the viewpoint of QCD dynamics: Namely, the intrinsic scale of QCD, $\Lambda_{\rm QCD} \sim 250$ MeV, is much smaller than $m_c(\sim 1.2\ \text{GeV}) \ll m_b(\sim 4.5\ \text{GeV})$. This property results in several interesting dynamical results.

1. Magnetic gluon coupling (the second term in Eq. (1)) is suppressed by a factor $(1/m_Q)$. Namely as (color electric coupling) $\gg$ (color magnetic coupling) the HQ spin-flip amplitudes are suppressed.

$$\bar{\Psi}\gamma^{\mu}\frac{\lambda^a}{2}\Psi A^a_{\mu} \sim \Psi^{\dagger}\frac{\lambda^a}{2}\Psi A^a_0 - \Psi^{\dagger}\boldsymbol{\sigma}\frac{\lambda^a}{2}\Psi \cdot \frac{1}{m_Q}\left(\nabla \times \boldsymbol{A}^a\right) \tag{1}$$

This is called heavy quark spin symmetry (HQSS). As the HQ spin is conserved, we will have spin doublets where $J = j_L \pm \frac{1}{2}$ partner states are degenerate in the HQ limit for a