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Study of excited quark propagator contributions in perturbative chiral quark model

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ABSTRACT

In this work, masses of octet baryons are evaluated in the framework of the perturbative chiral quark model (PCQM) with considering both the ground and excited states in the quark propagator, in which a Cornell-like potential is first constructed by letting the predetermined ground state quark wavefunction satisfy Dirac equation, and the excited quark states are derived by resolving Dirac equation with the extracted PCQM potential numerically employing Generalized Eigenvalue & Eigenstate Problem method. The results on the octet baryon masses are found in good agreement with the experimental data, and the study reveals that the contributions of the excited quark states are considerably influential in the octet baryon masses as expected.

1. Introduction

The perturbative chiral quark model (PCQM) is an indispensable tool in studies of the baryon structure and properties in the low-energy hadron physics [1–14]. In our previous works [13,14], we have employed the PCQM to investigate the electromagnetic and axial form factors as well as electroweak properties of octet baryons in the low energy region $Q^2 \leqslant 1\,\mathrm{GeV}^2$, in which a ground state quark wavefunction as shown in Fig. 1 has been determined by fitting the PCQM result of the proton charge form factor $G_E^p(Q^2)$ to the experimental data [13]. It is clear that the PCQM theoretical results

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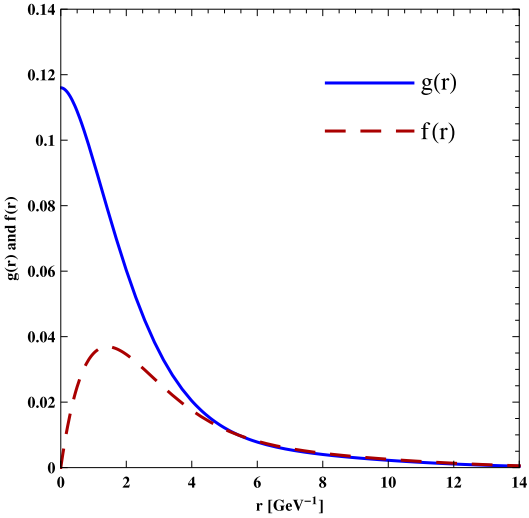

Fig. 1. Normalized radial wavefunction of the valence quarks for the upper component $g(r)$ (solid line) and the lower component $f(r)$ (dashed line) [13].

in Refs. [13,14] based on the predetermined ground state quark wavefunction are fairly consistent with the experimental data and lattice QCD values. That may indicate that the predetermined ground state quark wavefunction is reasonable and credible in the PCQM. In addition, Ref. [14] reports that the meson cloud contributes 30%–40% to the total values of the octet baryon axial charges, and the similar effects are also observed in other frameworks [15,16]. Thus these studies reveal that the virtual meson cloud plays a significant role. More discussions and results may be found in Refs. [13,14].

It is noted that only the ground quark state is determined and restricted in the quark propagator in our calculations [13,14]. As reported in Refs. [5,7], however, the excited quark states increase the contribution of the loop diagrams around 10% in comparison to 3q-core diagram in the PCQM. Thus we may propose that it is necessary to include the excited quark states in the propagator to investigate baryon properties. In addition, the mass of baryon, undoubtedly, is an essential quantity in nuclear and particle physics and has been of interest for many years [11,12,17–23]. Recently, the baryon mass spectra have been investigated accurately in the PCQM [11,12], the coupled-channel quark model [21], the unquenched quark model (UQM) [23]. These theoretical studies reveal that the meson cloud or $q\bar{q}$ pair reduces the baryon mass, but it is found that the ground state quark wavefunction is restricted in the quark propagator only in Refs. [11,12]. In the present work, thus we first construct the PCQM potential $V_{\text{eff}}(r)$ based on the predetermined ground state quark wavefunction, and then derive the ground and excited quark wavefunctions numerically with the extracted PCQM potential. Furthermore, we evaluate the octet baryon masses by means of the PCQM under SU(3) symmetry with including both the ground and excited states in quark propagator, and analyze the meson cloud and excited quark propagators contributions.

The paper is organized as follows. In Section 2, we extract the PCQM potential and the excited quark wavefunctions based on the predetermined ground state quark wavefunction. The numerical results and discussions on the octet baryon masses are presented in Section 3. Finally, we summarize and conclude this work in Section 4.

2. Potential and wavefunctions

In the framework of the PCQM, baryon is composed of three relativistic valence quarks (3q-core) and a cloud of pseudoscalar meson which is the sea-quark excitations. The quarks are moving in a