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Scalar and vector self-energies of heavy baryons in nuclear medium

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Abstract

The in-medium sum rules are employed to calculate the shifts in the mass and residue as well as the scalar and vector self-energies of the heavy Λ_Q, Σ_Q and Ξ_Q baryons, with Q being b or c quark. The maximum shift in mass due to nuclear matter belongs to the Σ_c baryon and it is found to be $\Delta m_{\Sigma_c} = -936$ MeV. In the case of residue, it is obtained that the residue of Σ_b baryon is maximally affected by the nuclear medium with the shift $\Delta\lambda_{\Sigma_b} = -0.014$ GeV^3. The scalar and vector self-energies are found to be $\Sigma^S_{\Lambda_b} = 653$ MeV, $\Sigma^S_{\Sigma_b} = -614$ MeV, $\Sigma^S_{\Xi_b} = -17$ MeV, $\Sigma^S_{\Lambda_c} = 272$ MeV, $\Sigma^S_{\Sigma_c} = -936$ MeV, $\Sigma^S_{\Xi_c} = -5$ MeV and $\Sigma^\nu_{\Lambda_b} = 436 \pm 148$ MeV, $\Sigma^\nu_{\Sigma_b} = 382 \pm 129$ MeV, $\Sigma^\nu_{\Xi_b} = 15 \pm 5$ MeV, $\Sigma^\nu_{\Lambda_c} = 151 \pm 45$ MeV, $\Sigma^\nu_{\Sigma_c} = 486 \pm 144$ MeV and $\Sigma^\nu_{\Xi_c} = 1.391 \pm 0.529$ MeV.

Keywords: Nuclear matter; Heavy hadrons; Mass; Residue; Scalar and vector self-energies

1. Introduction

The investigation of the in-medium properties of hadrons constituents one of the main directions of the research in high energy and particle physics both theoretically and experimentally. Such studies can help us not only better understand the structure of the hot and dense astrophys-

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ical objects like the neutron stars and analyze the results of the heavy ion collision experiments, but also get valuable knowledge on the perturbative and nonperturbative aspects of QCD and the nature of the quark–gluon plasma as the new phase of matter. From the experimental side, the PANDA and CBM Collaborations at FAIR aim to study the in-medium properties of not only the standard but also the non-conventional exotic states newly discovered by different collaborations [1–7].

From the theoretical side, it can be found many studies devoted to the in-medium properties of the light and heavy mesons as well as the light baryons (see for instance [8–21]). In the heavy baryon sector, however, there are few works dedicated to the investigation of the spectroscopic parameters of the heavy baryons in nuclear medium [22–24]. In these studies, the authors use the Ioffe current to study some properties of heavy and doubly heavy baryons.

In the present study, we use the interpolating currents with an arbitrary mixing parameter to investigate the shifts in the mass and pole residue of the heavy Λ_Q, Σ_Q and Ξ_Q baryons due to the nuclear medium. We employ the in-medium QCD sum rule approach to calculate also the scalar and vector self-energies of those baryons by fixing the mixing parameter entered the interpolating currents according to the standard prescriptions. We shall note that we do not analyze the heavy Ω_Q baryon here since the nuclear matter considered in the present work does not affect the parameters of the Ω_Q baryon considerably as it does not contain the u or d quark. One may investigate the shifts on the parameters of this baryon in hyperonic and strange matters or nuclear medium with strange component.

This work is organized as follows. In section 2, we obtain the in-medium QCD sum rules for mass and residue as well as the scalar and vector self-energies of the heavy Λ_Q, Σ_Q and Ξ_Q baryons in nuclear matter. In section 3, the numerical analyses of sum rules are performed and the results are compared with those of the vacuum and other predictions obtained via Ioffe currents in the literature. The last section contains our concluding remarks. Some lengthy expressions obtained during calculations are moved to the Appendix A.

2. Mass, residue and self-energies of heavy baryons in nuclear matter

In order to calculate the mass, residue as well as the scalar and vector self-energies of the heavy baryons using the QCD sum rule method in nuclear medium, the first step is to construct an in-medium two-point correlation function:

$$\Pi = i \int d^4x e^{ip\cdot x} \langle \psi_0 | T[J_{B_Q}(x) \bar{J}_{B_Q}(0)] | \psi_0 \rangle \tag{1}$$

where p is the four momentum of the heavy baryon, $|\psi_0\rangle$ is the nuclear matter ground state and J_{B_Q} is the interpolating current of the heavy $B_Q = \Lambda_Q, \Sigma_Q, \Xi_Q$ baryons. These interpolating currents are given as

$$\begin{aligned} J_{\Sigma_Q} &= -\frac{1}{\sqrt{2}} \epsilon^{abc} \Big\{ \Big(q_1^{aT} C Q^b \Big) \gamma_5 q_2^c + \beta \Big(q_1^{aT} C \gamma_5 Q^b \Big) q_2^c \\ &\quad - \Big[\Big(Q^{aT} C q_2^b \Big) \gamma_5 q_1^c + \beta \Big(Q^{aT} C \gamma_5 q_2^b \Big) q_1^c \Big] \Big\}, \\ J_{\Lambda_Q, \Xi_Q} &= \frac{1}{\sqrt{6}} \epsilon^{abc} \Big\{ 2 \Big(q_1^{aT} C q_2^b \Big) \gamma_5 Q^c + 2\beta \Big(q_1^{aT} C \gamma_5 q_2^b \Big) Q^c \\ &\quad + \Big(q_1^{aT} C Q^b \Big) \gamma_5 q_2^c + \beta \Big(q_1^{aT} C \gamma_5 Q^b \Big) q_2^c \\ &\quad + \Big(Q^{aT} C q_2^b \Big) \gamma_5 q_1^c + \beta \Big(Q^{aT} C \gamma_5 q_2^b \Big) q_1^c \Big\} \end{aligned} \tag{2}$$