Open Peer Review on Qeios

Possible K K bar Tetraquark Explanation for the f0(1370)

Joseph Bevelacqua

Funding: No specific funding was received for this work.
Potential competing interests: No potential competing interests to declare.

Abstract

Recent work by Peláez, Rodas, and Ruiz de Elvira suggest that the f_0(1370) structure is not well-defined. This paper investigates the description of this state in terms of a first-order K K bar tetraquark model. The model predicts the correct 0^+ assignment for the f_0(1370), but the calculated mass of 1079 MeV/c^2 falls below the experimental range of 1200 – 1500 MeV/c^2. The tetraquark description is not definitive, but it provides additional input to address the f_0(1370) structure issues noted by Peláez, Rodas, and Ruiz de Elvira.

1.0 Introduction

The low-energy quantum chromodynamics (QCD) region, including the lightest scalar spectrum, is of considerable interest[1,2]. As noted in Ref. 2, light scalars are important considerations in determining the characteristics of the nucleon-nucleon interaction, final states in heavy hadron decays, CP violation, the identification of the lightest glueball, and understanding spontaneous chiral symmetry breaking.

Light scalars generally are not observed as sharp resonances, since some of these states are broad and overlap[2]. The resonances can also be distorted by nearby two-body thresholds, and their shape can be altered by the dynamics of the creation process. Accordingly light scalars must be identified from process-independent associated poles.

As noted in Ref. 2, the peak shape only appears in the real axis when the resonance is narrow and isolated from other singularities. When this occurs, Breit-Wigner approximations, K matrices, or isobar sums may be utilized. However, this condition does not occur for the lightest scalars including the f_0(1370)[2].

In addition, the f_0(1370) remains controversial. Some research concludes that it well established, but other results do not concur[2]. As noted in Ref. 2, the nature of the f_0(1370) state is not firmly established. In addition, its mass is not yet well-established[18] with a range of 1200 – 1500 MeV/c^2.

Given the uncertainty in the characteristics of the f_0(1370), this paper investigates its structure in terms of a postulated K K bar tetraquark. A first-order tetraquark model has been successful in the description of a number of systems[3-14]. Accordingly, a description of the f_0(1370) using a first-order model is a reasonable approach to investigate its structure.

2.0 Model and Formulation

Zel'dovich and Sakharov[15,16] proposed a semiempirical mass formula that provides a prediction of mesons and baryons in terms of effective quark masses. Within this formulation, quark wave functions are assumed to reside in their lowest 1S state. These meson mass formulas are used as the basis for deriving a first-order tetraquark mass formula. In particular, the model proposed in this paper assumes the tetraquark is partitioned into two meson clusters with the interaction between the clusters providing a minimal contribution to the tetraquark mass.

The meson mass (M_m) formula of Refs. 3 - 14 is:

$$\mathbf{M_m = \delta_m + m_1 + m_2 + b_m [m_o^2 / (m_1 m_2)] \sigma_1 \cdot \sigma_2 \ (1)}$$

where m_1 (m_2) are the mass of the first (second) quark comprising the meson, m_0 is the average mass of a first generation quark[17,18], and the σ_i (i = 1 and 2) are the spin vectors for the quarks incorporated into the meson. The parameters δ_m and b_m are 40 MeV/c^2 and 615 MeV/c^2, respectively[16].

The last term in Eq. 1 represents the spin-spin interaction of the quarks and $\boldsymbol{\sigma_1 \cdot \sigma_2}$ is the scalar product of the quark spin vectors. $\boldsymbol{\sigma_1 \cdot \sigma_2}$ has the value -3/4 and +1/4 for pseudoscalar and vector mesons, respectively[16].

In formulating the tetraquark mass formula, effective quark masses provided by Griffiths[17] are utilized. These effective masses for d, u, s, c, b, and t quarks are 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively. The effective masses are utilized in Eq. 1.

These six quarks are arranged in three generations: [d(-1/3), u(+2/3)], [s(-1/3), c(+2/3)], and [b(-1/3), t(+2/3)][18]. The three generations are specified by the square brackets and the quark charges [in elementary charge units (e)] are given within parentheses.

3.0 First-Order Mass Formula for the f_0(1370)

The spin of a tetraquark within the first-order mass formula is determined by coupling the two meson clusters

$$\mathbf{J^\pi = J^\pi(1) \times L \times J^\pi (2)}$$

where the first-order mass formula assumes a minimally interacting L=0 configuration[3-14] between the meson clusters. Eq. 2 provides a primitive J^π assignment using the possible meson clusters. The $K^\pm$ and $K^\pm$ bar have a 0^- assignment. Applying Eq. 2, yields a $J^\pi = 0^- \times 0 \times 0^- = 0^+$ assignment in agreement with data[2, 18]. The K^+ (K^-) has a u s bar (u bar s) assignment.

The first-order mass formula used in this paper partitions the tetraquark into two meson clusters. These clusters include the $K^\pm$ and $K^\pm$ bar pseudoscalar mesons (sm). Using this structure, the tetraquark mass formula involving ground state meson clusters is assumed to have the form[3-14]

M ($K^{\pm}$ + $K^{\pm}$ bar) **=** $\mathbf{M_{sm}}$ **+** $\mathbf{M_{sm}}$ **+ Φ (3)**

where **Φ** defines the interaction between the meson clusters. Within the scope of this mass formula, the meson-meson cluster interaction is assumed to be weak and sufficiently small to be ignored. Accordingly, Eq. 3 represents the f_0(1370) structure as a quasimolecular four quark systems whose basic character is a weakly bound meson-meson system where the mesons reside in their ground states.

4.0 Results and Discussion

The angular momentum coupling from Eq. 2 and the first-order mass formula of Eqs. 1 and 3 are used to construct the f_0(1370) state. As noted previously, the spin and parity assignment for the f_0(1370) state is derived from Eq. 2. The resulting $J^{\pi} = 0^+$ assignment is in agreement with Refs. 2 and 18. As noted in Refs 3 – 14, the first-order mass formula only provides a primitive spin and parity assignment for the meson-meson cluster configuration.

Eqs. 1 and 3 lead to a predicted f_0(1370) mass of 1079 MeV/c^2. This result falls below the experimental range[18] of 1200 – 1500 MeV/c^2. Although this result is encouraging, it is based on a first-order mass formula with a number of uncertainties including the assumed quark masses[17], and the magnitude of the meson-meson cluster interaction. However, the model does provide an initial tetraquark description of the f_0(1370)[2]. The tetraquark description is not definitive, but it provides additional input to address the f_0(1370) structure issues noted in Ref. 2.

5.0 Conclusions

Recent work by Peláez, Rodas, and Ruiz de Elvira suggest that the structure of the f_0(1370) is not well-defined. Within the scope of a first-order tetraquark model, the f_0(1370)is predicted to have the correct 0^+ assignment, but the mass is 1079 MeV/c^2. The predicted mass falls below the experimental range of 1200 – 1500 MeV/c^2. The tetraquark description is not definitive, but it provides additional input to address the f_0(1370) structure issues noted by Peláez, Rodas, and Ruiz de Elvira.

References

1) J. R. Peláez and A. Rodas, Dispersive πK→πK and ππ→K Kbar amplitudes from scattering data, threshold parameters, and the lightest strange resonance κ or K^*_0(700), Phys. Rep. **969**, 1 (2022).

2) J. R. Peláez, A. Rodas, and J. Ruiz de Elvira, f_0(1370) Controversy from Dispersive Meson-Meson Scattering Data Analyses, Phys. Rev. Lett. **130**, 051902 (2023).

3) J. J. Bevelacqua, First-Order Tetraquark Mass Formula, Physics Essays **29**, 198 (2016).

4) J. J. Bevelacqua, Description of the X(5568) and Proposed 750 GeV/c^2 State in Terms of a First-Order Tetraquark

Mass Formula, Physics Essays **29**, 367 (2016).

5) J. J. Bevelacqua, Fusion of Doubly Heavy Mesons into a Tetraquark, Physics Essays **31**, 167 (2018).

6) J. J. Bevelacqua, Possible Tetraquark Explanation for the Proposed X(3872), Physics Essays **32**, 469 (2019).

7) J. J. Bevelacqua, Description of the X(6900) as a Four Charmed Quark State in Terms

of a First-Order Tetraquark Mass Formula, QEIOS **KLXLKJ**, 1 (2020).

https://doi.org/10.32388/KLXLKJ.

8) J. J. Bevelacqua, Description of the X(2900) as an Open Flavor Tetraquark in Terms of

a First-Order Mass Formula, QEIOS, **OVLMEB**, 1 (2020).

https://doi.org/10.32388/OVLMEB.

9) J. J. Bevelacqua, Possible Tetraquark Explanation for the Proposed $Z_{cs}(3985)^{-}$, QEIOS

GLTEU2, 1 (2021). https://doi.org/10.32388/GLTEU2.

10) J. J. Bevelacqua, Possible Tetraquark Explanation for the X(6200), QEIOS **J6AFYW**, 1 (2021).
https://doi.org/10.32388/J6AFYW.

11) J. J. Bevelacqua, Possible Tetraquark Explanation for the T_{cc}^{+}, Qeios **OMDGAQ**, 1 (2021).
https://doi.org/10.32388/OMDGAQ.

12) J. J. Bevelacqua, Possible Tetraquark Explanation for the Proposed $Z_{cs}(4000)^{+}$ and

$Z_{cs}(4220)^{+}$, Qeios **PPLMWV**, 1 (2021). https://doi.org/10.32388/PPLMWV.

13) J. J. Bevelacqua, Possible Tetraquark Explanation for the Proposed X(3960), Qeios,

O1L0YM, 1 (2022). https://doi.org/10.32388/O1L0YM.

14) J. J. Bevelacqua, Possible Tetraquark Explanation for the Proposed $T(2900)^{++}$

and $T(2900)^{0}$ Structures, Qeios **V6WLTS**, 1 (2022). https://doi.org/10.32388/V6WLTS.

15) Ya. B. Zel'dovich and A. D. Sakharov, *Kvarkovaia struktura i massy sil'novzaimodeistvuyushchikh chastits*, Yad. Fiz. **4**, 395 (1966).

16) A. D. Sakharov, Mass formula for mesons and baryons, Sov. Phys. JETP **51**, 1059 (1980).

17) D. Griffiths, *Introduction to Elementary Particles*, 2nd ed., (Wiley-VCH, Weinheim, 2008).

18) Particle Data Group, Review of Particle Physics, Prog. Theor. Exp. Phys. **2022**, 083C01 (2022).