RESEARCH ARTICLE

Pentaquark Model of the Neutral Λ(1405)

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Abstract

The structure of the $1/2^-$ $\Lambda^0(1405)$ resonance has been recently questioned by the Baryon Scattering Collaboration[1]. This state has been analyzed to suggest that it could be a resonance in the $\pi^-\Sigma^+$ spectrum. Given the proposed configuration, this paper investigates its structure in terms of a du-bar plus u u s pentaquark. The first-order pentaquark mass formula, based on the meson and baryon models of Zel'dovich and Sakharov, predicts the correct spin and parity for the $\Lambda^0(1405)$, and a mass within 5% of the measured value.

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1. Introduction

The Baryon Scattering Collaboration[1] notes that there is a lack of consensus regarding the character of the $1/2^-$ $\Lambda^0(1405)$. For example, there is a question regarding the presence of a single resonance or two adjacent resonances[1]. The character of this state has not been investigated in terms of a pentaquark structure. This is a logical investigation since the low-energy K^- p amplitude measured in bubble chamber experiments implies a resonance in the $\pi^-\Sigma^+$ spectrum[1].

A first-order pentaquark model has been developed and applied in previous studies. The model has provided reasonable predictions for the J^π values and masses in previous pentaquark studies[2][3][4][5][6][7].

2. Model Formulation

The first-order pentaquark mass formula is based on the semiempirical mass formulae of Zel'dovich and Sakharov[8][9]. This model weakly couples a meson and baryon to form the requisite pentaquark.

The meson mass formula has the form

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

In Eq. 1, the m_i (i = 1 and 2) are the masses of the quarks comprising the meson cluster, m_0 is the average mass of a first generation quark (u and d) [10][11], and the σ_i are the spin vectors for the associated quarks. 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[9]. Completing the specification of Eq. 1 are the parameters δ_m and b_m defined by Zel'dovich and Sakharov[8][9] that have the values 40 MeV/c^2 and 615 MeV/c^2, respectively[9].

Eq. 1 utilizes effective quark masses determined by Griffiths[10] for d, u, s, c, b, and t quarks that have the values 340, 336, 486, 1550, 4730, and 177000 MeV/c^2, respectively. Following standard convention[10][11], the quarks are grouped into three generations: [d(-1/3), u(+2/3)], [s(-1/3), c(+2/3)], and [b(-1/3), t(+2/3)][10][11]. Quark charges, in terms of the unit charge e, are given within the parentheses.

In a similar manner, the pentaquark mass formula has the form

$$M_b = \delta_b + m_1 + m_2 + m_3 + (b_b/3)\{[m_o^2/(m_1 m_2)]\sigma_1 \cdot \sigma_2 + [m_o2/(m_1 m_3)]\sigma_1 \cdot \sigma_3 + [m_o^2/(m_2 m_2)]\sigma_2 \cdot \sigma_3\} \qquad (2)$$

where the labels 1, 2, and 3 identify the three quarks comprising the baryon. The parameters δ_b and b_b are defined by Zel'dovich and Sakharov[8][9] that have the values 230 MeV/c^2 and 615 MeV/c^2, respectively[9]. For a particle with a total baryon spin J = ½ and two identical quarks (q_2 and q_3), the following particle spin vector products apply:

$\sigma_2 \cdot \sigma_3 = ¼$ and $\sigma_1 \cdot \sigma_3 = \sigma_1 \cdot \sigma_2 = -1/2$[9].

3. Pentaquark Model of the Λ^0(1405)

The first-order mass formula for a pentaquark provides a primitive spin assignment by combing the meson (π^-, $J^\pi = 0^-$) and baryon (Σ^+, $J^\pi = 1/2^+$) with zero angular momentum between the clusters

$$J^\pi = 0^- \times 0 \times 1/2^+ = 1/2^- \qquad (3)$$

Eq. 3 provides the correct $1/2^-$ assignment for the Λ^0(1405).

The Λ^0(1405) mass is defined in terms of the meson and baryon masses

$$M[\Lambda^0(1405)] = M(\pi^-[du-bar]) + M(\Sigma^+[uus]) + \Phi \qquad (4)$$

where the quark content of the meson and baryon are provided in the brackets, the pion (sigma plus) mass is determined from Eq. 1 (2), and Φ is the interaction potential between and meson and baryon clusters. In Eq. 4, Φ is assumed to be much smaller than the masses appearing in Eq. 4.

Using Eq. 4 and the quark masses from Ref. 10 leads to a first-order mass prediction of 1471.1 MeV/c^2. This result is within 5% of the experimental Λ^0(1405) mass of 1405.1 MeV/c^2.

4. Conclusions

A first-order pentaquark mass formula is used to predict the Λ^0(1405) mass. The model weakly couples the π^-meson and Σ^+ baryon. By assuming zero angular momentum between the clusters, the pentaquark model leads to a predicted J^π value of $1/2^-$ that is in agreement with experiments. The predicted first-order model mass is within 5% of the measured value. These results suggest that the Λ^0(1405) is reasonably well modeled as a pentaquark. However, that contention has not been experimentally observed.

References

1. a, b, c, d *Baryon Scattering Collaboration. Two-Pole Nature of the Λ(1405) Resonance from Lattice QCD. Phys. Rev. Lett. 132, 051901 (2024).*
2. ^ *Bevelacqua JJ. First-Order Pentaquark Mass Formula. Physics Essays 29, 107 (2016).*
3. ^ *Bevelacqua JJ. Possible Description of the J/Ψ p and J/Ψ p-bar Structures in Terms of a First-Order Pentaquark Mass Formula. Qeios 6KVPY6, 1 (2022). doi:10.32388/6KVPY6.*
4. ^ *Bevelacqua JJ. Possible Description of the J/Ψ Λ Structure at 4338.2 MeV in Terms of a First-Order Pentaquark Mass Formula. Qeios HDEA44, 1 (2022). doi:10.32388/HDEA44.*
5. ^ *Bevelacqua JJ. Possible Description of the J/Ψ Ξ (S = -2) Structure in Terms of a First-Order Pentaquark Mass Formula. Qeios HL8ISX, 1 (2023). doi:10.32388/HL8ISX.*
6. ^ *Bevelacqua JJ. Possible f Quark Model of Tetraquarks and Pentaquarks. Qeios, 8T3IVE, 1 (2023). doi:10.32388/8T3IVE.*
7. ^ *Bevelacqua JJ. Possible Description of the Excited States of the Neutral Charmed Omega in Terms of a First-Order Pentaquark Mass Formula. Qeios MU0ID5, 1 (2024). doi:10.32388/MU0ID5.*
8. a, b, c *Zel'dovich YB, Sakharov AD. Kvarkovaia struktura i massy sil'novzaimodeistvuyushchikh chastits. Yad. Fiz. 4, 395 (1966).*
9. a, b, c, d, e, f, g *Sakharov AD. Mass formula for mesons and baryons. Sov. Phys. JETP 51, 1059 (1980).*
10. a, b, c, d *Griffiths D. Introduction to Elementary Particles, 2nd ed., (Wiley-VCH, Weinheim, 2008).*
11. a, b, c *Particle Data Group. Review of Particle Physics. Phys. Rev. D 110, 030001 (2024).*