Description of the Ξb⁻ (6100) Baryon in Terms of a First-Order Mass Formula

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

Abstract

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A recently proposed Ξb⁻ (6100) baryon structure is investigated using a first-order mass formula. The first-order mass formula predicts the Ξb⁻ (6100) baryon has a mass of 5710 MeV/c². This prediction is about 6% smaller than the experimental value. The first-order mass formula also predicts possible Jπ values of 1/2⁺ and 3/2⁺ for the proposed Ξb⁻ (6100) baryon. This is consistent with the experimental Jπ value of 1/2⁺.

KEYWORDS: Ξb⁻ (6100) baryon, mass formula, quark model, cluster model

1.0 Introduction

The original set of baryons was defined by the octet and decuplet structures that contain u, d, and s quarks. This basic set of states has expended with the inclusion of the heavier c, b, and t quarks. For example, the Ξ⁻ baryon is composed of a d quark and two s quarks. Analogue Ξb baryons form an isospin doublet and contain a b quark, an s quark and a lighter q (u or d) quark¹. As noted in Ref. 1, the Ξb⁻ baryon ground states have no angular momentum between the b quark and the light diquark.

The Ξb⁻ (6100) baryon has been recently confirmed by the LHCb Collaboration¹ utilizing an evaluation of the Ξb⁻ π⁺ π⁻ system. Following Ref. 1, The Ξb⁻ (6100) baryon has a Jπ value of 1/2⁺, and a mass of 6100 MeV/c².

This paper applies the first-order mass formula model of Refs. 2 and 3 to investigate the Ξb⁻ (6100) baryon. The proposed methodology was previously used to evaluate pentaquark⁴-⁶, and hexaquark and other exotic quark configurations⁷-⁹ that incorporates the first-order mass formula.

2.0 Model Formulation

Zel'dovich and Sakharov²,³ proposed a semiempirical mass formula that provides a prediction of meson and baryon masses in terms of effective quark masses. Within this formulation, quark wave functions are assumed to reside in their
The baryon mass formula is used as the basis for deriving a $\Xi_b^- (6100)$ baryon mass.

The baryon (b) mass (M) formula of Refs. 2 and 3 is:

$$M_b = \delta_b + m_1 + m_2 + m_3 + Z(1a)$$

$$Z = \left[ \frac{b_1 m_0^2 m_1 m_2}{3 m_1 m_2} \sigma_1 \cdot \sigma_2 + \frac{m_0^2 m_1 m_3}{m_1 m_3} \sigma_1 \cdot \sigma_3 + \frac{m_0^2 m_2 m_3}{m_2 m_3} \sigma_2 \cdot \sigma_3 \right] (1b)$$

where the $m_i$ labels the three baryon quarks ($i = 1, 2, 3$) and $\delta_b$ and $b_b$ are 230 MeV and 615 MeV, respectively. For a particle with a total baryon spin 1/2, the following prescription is used if the baryon (comprised of three quarks $q_1, q_2,$ and $q_3$) contains two identical quarks $q_2$ and $q_3$

$$\sigma_2 \cdot \sigma_3 = 1/4 \quad (2)$$

$$\sigma_1 \cdot \sigma_2 = \sigma_1 \cdot \sigma_3 = -1/2 \quad (3)$$

For completeness, the reader should note that $q \cdot q_j$ has the value +1/4 for a J= 3/2 baryon. In addition, these basic $q \cdot q_j$ relationships must be modified if the baryon contains three different quarks. The methodology is provided in Ref. 3.

In formulating the baryon mass formula, effective quark masses provided by Griffiths 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. These masses are utilized in Eq. 1.

These six quarks are arranged in three generations: [d(-1/3 e), u(+2/3 e)], [s(-1/3 e), c(+2/3 e)], and [b(-1/3 e), t(+2/3 e)]

The first-order mass formula model only permits a primitive coupling structure between the quarks

$$J^\pi(\Xi_b^-(6100)) = 1/2^+ \times 1/2^+ \times 1/2^+ \quad (4)$$

The values utilized in Eq. 4 suggest possible $J^\pi = 1/2^+$ and $3/2^+$ values. Eq. 4 does not uniquely predict the total angular momentum of the $\Xi_b^- (6100)$ baryon, but does permit a range of spin coupling values to be predicted.

### 3.0 Results and Discussion

Eq. 1 is used to calculate the mass of the $\Xi_b^- (6100)$ baryon. The first-order-mass formula predicts $\Xi_b^- (6100)$ baryon has a mass of 5710 MeV/c$^2$.

Using Eq. 4, the first-order mass formula predicts $J^\pi$ values of 1/2$^+$ and 3/2$^+$ for the $\Xi_b^- (6100)$ baryon. This is consistent with the 1/2$^+$ prediction of Ref. 1. The first-order mass is about 6% smaller than the experimental value of Ref.
4.0 Conclusions

A recently proposed $\Xi_b^-$ (6100) baryon structure is investigated using a first-order mass formula. The first-order-mass formula predicts the $\Xi_b^-$ (6100) baryon has a mass of 5710 MeV/$c^2$. This prediction is about 6% smaller than the experimental value. The first-order mass formula also predicts possible $J^\pi$ values of $1/2^+$ and $3/2^+$ for the proposed $\Xi_b^-$ (6100) baryon. This is consistent with the experimental $J^\pi$ value of $1/2^+$.

References

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