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

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Abstract

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A recently proposed Ξ_b^- (6100) baryon structure is investigated using a first-order mass formula. The first-order-mass formula predicts the Ξ_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^π values of $1/2^+$ and $3/2^+$ for the proposed Ξ_b^- (6100) baryon. This is consistent with the experimental J^π value of $1/2^+$.

KEYWORDS: Ξ_b^- (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 Ξ_b baryons form an isospin doublet and contain a b quark, an s quark and a lighter q (u or d) quark[1]. As noted in Ref. 1, the Ξ_b baryon ground states have no angular momentum between the b quark and the light diquark.

The Ξ_b^- (6100) baryon has been recently confirmed by the LHCb Collaboration[1] utilizing an evaluation of the $\Xi_b^- \pi^+ \pi^-$ system. Following Ref. 1, The Ξ_b^-(6100) baryon has a J^π value of $1/2^+$, and a mass of 6100 MeV/c^2.

This paper applies the first-order mass formula model of Refs. 2 and 3 to investigate the Ξ_b^- (6100) baryon. The proposed methodology was previously used to evaluate pentaquark[4-6], and hexaquark and other exotic quark configurations[7-9] that incorporates the first-order mass formula.

2.0 Model Formulation

Zel'dovich and Sakharov[2,3] 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 lowest S state. The baryon mass formula is used as the basis for deriving a Ξ_b^- (6100) baryon mass.

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

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

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

where the m_i labels the three baryon quarks (i = 1, 2, and 3) and δ_b and b_b are 230 MeV and 615 MeV, respectively[3]. 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[3] q_2, and q_3

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

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

For completeness, the reader should note that $\sigma_i \cdot \sigma_j$ has the value +1/4 for a J= 3/2 baryon. In addition, these basic $\sigma_i \sigma_j$ 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[10] 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(-1/3e), t(+2/3 e)] [11]. The three generations are specified by the square brackets and the quark charges are given within parenthesis in terms of the proton charge e.

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

$J^\pi(\Xi_b^-$ (6100)) = ½⁺ x ½⁺ x ½⁺ (4)

The values utilized in Eq. 4 suggest possible J^π = 1/2⁺ and 3/2 ⁺ values. Eq. 4 does not uniquely predict the total angular momentum of the Ξ_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 Ξ_b^- (6100) baryon. The first-order-mass formula predicts Ξ_b^- (6100) baryon has a mass of 5710 MeV/c^2.

Using Eq. 4, the first-order mass formula predicts J^π values of $1/2^+$ and $3/2^+$ for the Ξ_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.

1.

4.0 Conclusions

A recently proposed Ξ_b^- (6100) baryon structure is investigated using a first-order mass formula. The first-order-mass formula predicts the Ξ_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^π values of $1/2^+$ and $3/2^+$ for the proposed Ξ_b^- (6100) baryon. This is consistent with the experimental J^π value of $1/2^+$.

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